MOISTURE RETENTION CHARACTERISTICS OF SIX WESTERN KANSAS SOILS IN RELATION TO CLAY CONTENT AND SURFACE AREA

by

ROBERT EDWARD MORIN

B. S., Kansas State University
of Agriculture and Applied Science, 1959

A THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Agronomy

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1961

LD
2668
T4
1961
M67
c.2
Documents

TABLE OF CONTENTS

INTRODUCTION 1

LITERATURE REVIEW 1

Surface Area 1

Soil Moisture 8

Mechanical Analysis 12

MATERIALS 14

Soils 14

Reagents 14

Equipment 15

METHODS 15

Surface Area 15

Surface Area by Sor and Kemper's Method 15

Surface Area by the Proposed Method 16

Particle Size Analysis 18

Moisture at Four Tension Levels 18

Organic Matter 19

Calculations 19

Statistical Methods 20

RESULTS AND DISCUSSION 21

Chemical Analyses 21

Surface Area 22

Method Comparison 22

Organic Matter Effect 23

Use of Proposed Method 26

Use of Sor and Kemper's Method 27

Comparison of Proposed and Sor and Kemper's Method for Specific Surface Area 31

Surface Area of Size Fractionated Bentonite 32

Fractionation Procedure 32

Surface Area by Sor and Kemper's Method 33

X-ray of Bentonite 35

Soil Texture 36

Percent Clay and Surface Area 37

Percent Sand, Silt, or Clay with Surface Area 41

Comparisons Between Percent Sand, Silt, Clay, and Organic Matter 43

Moisture Retention at Four Tension Levels 44

Percent Clay and Moisture Retention 45

Moisture Retention and Range of Available Water .. 50

Sand, Silt, Organic Matter, and Moisture Retention 51

Relationships Between Surface Area and Moisture Retention 52

Multiple Regression Analysis Using Three, Four, and Five Variables 54

Three Variables 54

Four Variables 57

Five Variables 58

SUMMARY 59

CONCLUSIONS 62

ACKNOWLEDGMENTS 63

LITERATURE CITED 64

APPENDIX 67

INTRODUCTION

Data from the Soil Survey Laboratory at Lincoln, Nebraska suggested that moisture retention properties of soils could be predicted from soil physical properties. This study was undertaken to determine which physical properties were most closely related to moisture retention characteristics of six western Kansas soils.

The chemical properties of the soils selected have recently been investigated but little data about physical properties of any western Kansas soils are known.

LITERATURE REVIEW

Surface Area

Montmorillonite and endellite, the hydrateable form of halloysite, are the only clay minerals that form definite solvates with polar molecules between the structural layers (Dyal and Hendricks (16). Wyoming bentonite, the clay used in this study, is a montmorillonite type clay sold under the trade name "Volclay." According to Martin (24), layer hydrates of montmorillonite contain one to possibly four layers of water molecules. He stated that water is the most important polar liquid that is adsorbed by clays, but to date its use has not been adapted to study the surface area of soil clays.

Sor and Kemper (33) stated that retention and adsorption of ethylene glycol is one of the easiest and most precise ways to

estimate hydrateable surface areas of soil and clay samples. They defined hydrateable surface area as that area which will be hydrated under normal soil conditions. For a montmorillonite type clay, each surface is considered to be 100 percent hydrated when two layers of water molecules are adsorbed between adjacent platelets. Ethylene glycol is adsorbed in essentially the same manner and on the same mineral surfaces as water. Water has a relatively high vapor pressure, and has a strong tendency to continue crystal lattice formation in the c dimension. Ethylene glycol has a much lower vapor pressure than water and has less tendency to continue crystal lattice formation in the c dimension (Sor and Kemper, 33). Bradley (10) and MacEwan (23) found that the c spacing of montmorillonite increased from about 9.8 Å when oven dry to 17.2 Å when saturated with ethylene glycol. MacEwan (23) pointed out that this changed spacing corresponded to the spacing that would occur if two layers of ethylene glycol molecules had been inserted in the basal plane of the clay particles. Sor and Kemper (33) used the value 3.7 Å as the thickness of a monolayer of ethylene glycol adsorbed on a clay surface. This value corresponds to the value determined by Bradley and MacEwan.

According to Martin (24), polyhydroxylic aliphatic compounds form fairly stable two-layer solvates with montmorillonite. These compounds have been used for the identification of this mineral by X-ray diffraction. Barshad (1) has also observed interlayer expansion in montmorillonite due to adsorption of various organic substances. Ethylene glycol, glycerol, and other

polyhydroxylic aliphatic compounds have been shown by Bradley (10) and MacEwan (23) to form two-layer solvates in the presence of excess solvent. These solvates are relatively stable under desiccation or exposure to moist air.

Bradley (10) added ethylene glycol to montmorillonite, and took X-ray diffractions of the resulting mixtures. It appeared that the ethylene glycol formed a single monolayer on each hydrateable surface, giving a duo-layer between plates.

According to Barshad (1), interlayer expansion is related to the magnitude of the dipole moment and the dielectric constant of the interlayer substance. MacEwan (23), Dyal and Hendricks (16), and Sor and Kemper (33) stated that ethylene glycol adsorbed between the soil clay plates has a lower vapor pressure than free ethylene glycol. Free ethylene glycol can be evaporated rapidly, but the rate of evaporation decreases sharply when only adsorbed ethylene glycol is retained on the clay. This phenomenon formed the basis for a method of measuring specific surface proposed by Dyal and Hendricks (16).

Bradley (10), MacEwan (23), Dyal and Hendricks (16), and Sor and Kemper (33) concluded that ethylene glycol is adsorbed in a monomolecular layer both between clay platelets and on external clay surfaces. The vapor pressure of adsorbed ethylene glycol is about the same in each instance (Sor and Kemper, 33).

The Brunauer, Emmett, and Teller (13) method was one of the earliest methods used for the determination of specific soil surface. This method depends upon adsorption of a simple molecule

such as nitrogen at temperatures lowered to the vicinity of the boiling point. Nelson and Hendricks (26) used the gas adsorption method to determine the specific surface area of clay minerals and soil colloids. Their values were in close agreement with values obtained from electron micrographs.

Dyal and Hendricks (16) proposed a simple gravimetric method which makes use of the two-layer solvate formed by ethylene glycol for determination of internal swelling and total surface area of clays. Ethylene glycol saturated clay samples were placed over anhydrous $CaCl_2$ in a desiccator. The desiccator was evacuated to less than 0.1 mm. Hg pressure. A monolayer of ethylene glycol was judged to be left on all hydrateable surfaces when the vapor pressure of ethylene glycol dropped sharply, causing a sharp decrease in removal rate of ethylene glycol. They reasoned that amounts of ethylene glycol retained at this point corresponded to a monolayer on all surfaces and that this value could be used as a quantitative estimate of total surface area. They concluded by experiment and calculation that 0.0031 gram of ethylene glycol represented an adsorbed monolayer on a square meter of clay surface.

Dyal and Hendricks (16) and Bower and Gschwend (8) reported that ethylene glycol retention by soils and clays correlates well with external specific surface measurement by the Brunauer, Emmett, and Teller gas adsorption method. The ethylene glycol adsorption method is less laborious than the gas adsorption method of determining surface area.

Bower and Gschwend (8) determined gravimetrically amounts of ethylene glycol retained on clay and soil surfaces by following ethylene glycol losses from samples initially saturated and then subjected to high vacuum over dry $CaCl_2$. A monolayer was judged to be left on the clay surfaces when loss in weight per hour was less than 3 or 4 percent of the weight of ethylene glycol retained.

Dyal and Hendricks' method was modified by Martin (24). Free ethylene glycol was placed in the chamber during desiccation so equilibrium would be attained and successive weighings avoided. Equilibrium was obtained in a relatively short time under these conditions but amounts of ethylene glycol retained was greater than that determined by Bower and Gschwend's method.

Sor and Kemper (33) proposed a modification of ethylene glycol retention methods for estimating hydrateable surface area. The modification makes the following assumptions: soil samples will retain a monolayer of adsorbed ethylene glycol at equilibrium provided a source of ethylene glycol with vapor pressure equal to that of an adsorbed monolayer is present during the desiccation process. Buffer mixtures of commercial Wyoming bentonite and ethylene glycol can be used to obtain the proper vapor pressure. Amounts of ethylene glycol used in the buffer mixture should be the amount required to form the monolayer as determined by Bower and Gschwend's method (8).

Briefly, the procedure is as follows: dry and ethylene glycol saturated samples are placed in a desiccator over a large

amount of buffer and the desiccator evacuated to less than 2 mm. Hg. The samples gain and lose ethylene glycol, respectively until at equilibrium they retain approximately one monolayer of ethylene glycol on all hydrateable surfaces. Average amounts of ethylene glycol retained at equilibrium by the two samples is used to calculate total hydrateable surface area.

Bower and Goertzen (9) also proposed an equilibrium method for measuring surface area of soils and clays. Ethylene glycol saturated soil samples are placed over a $CaCl_2$-ethylene glycol solvate buffer in a desiccator which is then evacuated. Attainment of equilibrium is hastened by placing the $CaCl_2$-ethylene glycol solvate and soil samples in a culture chamber to shorten the mean diffusion path of ethylene glycol vapor. Results obtained in this manner agree closely with values obtained by non-equilibrium methods. They showed experimentally that ethylene glycol forms a monosolvate with $CaCl_2$. Mixtures of anhydrous $CaCl_2$ and solvated $CaCl_2$ as well as the mixtures of two solvated forms of $CaCl_2$ salts have definite vapor pressures at given temperatures. This vapor pressure is independent of relative amounts of the two salt forms present. Fresh $CaCl_2$-ethylene glycol solvate is required for each set of determinations, since it is almost impossible to prevent adsorption of atmospheric water. Only four determinations can be made concurrently using one solvate mixture.

Martin (24) showed that more water is removed from soil or clays by oven drying than is removed by drying over P_2O_5 even

though the samples are left over P_2O_5 until a constant weight is attained. Calcium montmorillonite samples were dried at 217° C for 39 and 111 hours; other samples were placed over evacuated P_2O_5 for five hours. The oven-dried samples lost 3 percent more water than did samples placed over P_2O_5. Samples placed over P_2O_5 retained 290 milligrams of ethylene glycol per gram of clay. Oven-dried samples retained 305 $\pm$ 3 milligrams ethylene glycol per gram of clay. Oven drying at these high temperatures definitely increased ethylene glycol retention values.

Dyal and Hendricks (16) calculated total layer surface area of montmorillonite less than two microns in diameter on the basis of the dimensions of a unit cell. The calculated value was 810 square meters surface per gram of montmorillonite.

Amounts of ethylene glycol retained by less than 2 micron bentonite was 0.250 gram per gram of clay. Assuming the sample was pure montmorillonite and one gram exposed 810 square meters of surface, then 0.00031 gram of ethylene glycol adsorbed represents one square meter of surface. The value 3.1×10^{-4} gram ethylene glycol per square meter of surface was used to determine the corresponding area per ethylene glycol molecule which is 33×10^{-16} square cm. Bradley (10) determined the electron distribution in the layer solvates. The value 33×10^{-16} square cm. per molecule of ethylene glycol is consistent with ethylene glycol molecules lying with CH_2 and OH groups upon the surface.

According to Sor and Kemper (33) the density of one monolayer of ethylene glycol adsorbed on clay surfaces would be

0.83 gm./cm.^{3}, if it were assumed that, (a) 0.00031 grams of ethylene glycol is adsorbed per square meter of surface, (b) the thickness of one monolayer is 3.7 Å, and (c) that ethylene glycol covers all surfaces and no clay platelets are "stuck together." Density of free ethylene glycol is 1.11 gm./cm.^{3} Such a change in density is much larger than is usually associated with adsorption of liquids on solid surfaces. This discrepancy merits further investigation because it indicates that the calculated surface area of montmorillonite is too large, that ethylene glycol does not form complete monolayers on all surfaces, or that the montmorillonite used was not pure.

Jackson (19) calculated total surface area of montmorillonite to be 808.6 m.^{2}/gm. According to his analysis, total surface area is distributed as follows: specific planar surface, 808 m.^{2}/gm.; external surface, 3.64 m.^{2}/gm.; edge surface, 0.61 m.^{2}/gm.; and internal surface, 805 m.^{2}/gm. Total surface area is equal to specific planar surface plus edge surface or 808.6 m.^{2}/gm. Internal surface area was determined by subtracting external surface from total surface area. Jackson's values are based on the assumption that montmorillonite unit cells measure 5.25 Å by 9.20 Å and that edge height of clay particles is 0.1 the diameter.

Soil Moisture

Percent moisture is a measure of the amount of water in soil. Soil moisture tension is a measure of the force required to remove water from soil. According to Richards and Weaver (32),

various terms have been used for indicating the capacity of soils to retain water, e.g., water holding capacity, moisture equivalent, field capacity, and various wilting percentages. Amounts of water available to plants can be determined only if both percent moisture and soil moisture tension are known.

The water in a glass or soil capillary is held by a suction force commonly called moisture tension. Soil moisture tension has also been described as a negative pressure since the hydrostatic pressure in soil or glass capillaries is less than zero. This tension may be expressed in any convenient pressure unit such as dynes/cm.^{2}, pounds per square inch or atmospheres.

According to Richards (27, 30), removal of water from soil by suction is accomplished by connecting the liquid phase of water in the soil with liquid water at a lower pressure. Water always moves to the region of lowest pressure. Porous ceramic, cellophane, cellulose, or other suitable membranes may be used as a help in maintaining a pressure difference between extracted water and water in soils.

The ordinary range of soil moisture tension encountered with growing plants ranges from 1/3 to 31 atmospheres. Since suction forces obtainable in the laboratory do not exceed one atmosphere, most devices for measuring soil moisture tension over the ordinary soil range utilizes a positive pressure differential to remove water from the soil. When water in a soil capillary is subjected to a pressure differential, water moves from the capillary until the soil moisture tension holding water in the

capillary just equals the positive pressure applied.

Richards (27, 30) and Richards and Fireman (31) stated that when equilibrium is reached and water ceases to pass through the membrane, the interface curvature of the water throughout the soil will be equal to that at the membrane. Under these conditions more water cannot be removed from the soil unless the pressure is increased.

To make the determination, the soil is placed in a pressure chamber on a suitable membrane which forms the bottom of the pressure chamber. The membrane serves as a device to obtain a pressure differential. Air pressure above the membrane is built up to the desired level while air pressure below the membrane is maintained at atmospheric pressure. The pore size of the membrane determines the amount of pressure that can be applied because the membrane must remain saturated with water in order to maintain the pressure differential. Increases in the pressure differential causes water to flow from the saturated membrane which increases the tension of the water in the membrane pores. The increased tension causes water to flow from the soil toward the plate. The moisture tension in both the membrane and soil come to equilibrium with that of the applied pressure if the pressure is kept constant.

Porous ceramic plates are successfully used as membranes from 0 to 2.0 atmospheres while cellulose (Visking) membranes have been used for pressures from 1 to greater than 100 atmospheres.

Richards and Fireman (31), Richards and Weaver (32), and Richards (28, 30) agreed that the pressure membrane apparatus is identical in principle with the pressure plate apparatus.

The 1/3 atmosphere percentage, according to Richards and Weaver (32), is the percentage of moisture retained in a soil subjected to the following treatments: (a) air drying, (b) passage through a 2 mm. round hole sieve, (c) wetting for a minimum of six hours with an excess of water on a porous plate, and (d) bringing to equilibrium at 1/3 atmosphere pressure.

The percent water at either a tension of 1/3 atmosphere or at the moisture equivalent has been widely accepted as representing field capacity in soils. Colman (14) found the 1/3 atmosphere percentage to be considerably lower than field capacity in coarse soils, equal to field capacity at moisture values around 20 percent, and somewhat higher than field capacity in finer-textured soils. Browning (12) found moisture equivalent to be equal to field capacity at about 21 percent moisture. Moisture equivalent values were lower than field capacity for coarse soils, and higher than field capacity for fine-textured soils.

Richards and Weaver (32) listed factors affecting moisture contents of soils at field capacity as follows: (a) nature and condition of the whole profile including the original moisture distribution, (b) moisture transmitting properties of the soil, (c) moisture retaining properties of the soil, and (d) amount of water applied to the soil. They recommended the 1/3 atmosphere

moisture percentage as a good laboratory measure for approximating field capacity.

Richards and Weaver (32); Colman (14); Haise, Haas, and Jensen (18); and Lund (22) all concluded that soil moisture retained against a tension of 1/3 atmosphere closely approximates moisture equivalent.

Mechanical Analysis

Bouyoucos (2, 3) realized the need for a simple, rapid method for determining amounts of colloidal material in soils. The hydrometer method was developed in 1927 and has achieved considerable popularity in soil laboratories where particle size distribution is determined. Both physical and chemical characteristics of a soil are influenced by the size and proportions in which the various sized particles are present. Soil water holding capacity, capillary movement of water, availability of water, and soil surface area are all dependent upon soil particle size distribution. Particle size analysis was necessary in order to determine the effect of sand, silt, and clay on surface area and water retention.

Two ways of performing mechanical analyses are the Bouyoucos hydrometer and the pipette method. The latter method is used exclusively by U.S.D.A. Soil Survey Laboratories and is accepted as being accurate but time consuming. The Bouyoucos method was used in this study because of the simplicity and the rapidity of the determination.

In the Bouyoucos hydrometer method, the soil is dispersed and allowed to settle in a special cylinder. As the soil particles settle, the density of the suspension changes. A hydrometer is used to measure the changes in density after given settling times. Density measurements have been related to sand and clay concentrations in the suspensions. Bouyoucos (4) considers the method to be quantitative and reliable for soils that are properly dispersed. The method is most accurate for soils with uniform size distribution of particles below 2 mm. in size.

According to Bouyoucos (7), mechanical analysis is influenced by degree of stirring, dispersing agent, pre-treatment, and soil composition. Good soil dispersion is obtained using sodium hexametaphosphate as the chemical dispersing agent and a malted milk machine which will idle at 16,000 to 18,000 r.p.m. for mechanical dispersion. Baffles placed in the mixing cup aid in the dispersion process.

Agreement between pipette and Bouyoucos hydrometer method has been good where soil organic matter was low (Bouyoucos, 5). Kilmer and Alexander (21) found discrepancies between the two methods for surface soils high in organic matter. These investigators found that pipette analysis gave higher clay percentages for soils high in organic matter than did the Bouyoucos method. This was attributed to better dispersion due to organic matter removal in the pipette method. However, Bouyoucos analyzed several problem soils submitted by the U.S. Bureau of Chemistry and Soils and agreement between his method and analysis by the

U.S. Bureau of Chemistry and Soils, using the pipette method, was very good. On this basis it can be concluded that the two methods give comparable results.

MATERIALS

Soils

Soils used for this study were loess derived and had been sampled previously for chemical analyses. Chemical analyses were determined by Dixon (15) and Naddih (25). These soils were sampled by horizon, and detailed descriptions by Soil Conservation Service technicians are given in preceding references. Soil type names were: "Spearville silty clay loam"; "Syracuse clay loam", recently correlated as Bayard clay loam; Richfield silt loam; Ulysses silt loam; "Harney silt loam"; and Kieth silt loam. These soils are important soil types in western Kansas. The soils were sampled in Haskell, Hamilton, Grant, Gray, and Wallace Counties. A summary of the chemical analyses and legal descriptions of the sites are given in Tables 8 and 9 (Appendix), respectively.

Reagents

Chemicals used for surface area determinations were: ethylene glycol (Fisher sp. gr. 1.113 gm./cm.^{3}), 8 mesh anhydrous $CaCl_2$ (reagent grade), and phosphoric anhydride P_2O_5. The ethylene glycol is redistilled under reduced pressure, and the first and last 10 percent of the distillate discarded. Wyoming

bentonite, a montmorillonite type clay, sold under the trade name Volclay, was the clay standard used in this study. This clay was used in the buffer mixture and for check samples for determining surface area.

Equipment

Equipment used in surface area analyses included vacuum desiccators 25 cm. in diameter, a Duo Seal vacuum pump to reduce pressure within the desiccators to 0.5 mm. Hg, aluminum moisture cans 6 cm. in diameter, and analytical and triple beam balances. A McLeod gauge was used to determine pressure within the system. The vacuum pump and desiccators were connected by a system of glass and rubber hose tubing. The glass-rubber hose connections were sealed with hard wax.[1] Vacuum grease was used to seal the desiccators.[2] A glass tube filled with 8-mesh anhydrous $CaCl_2$ was installed between the vacuum pump and desiccator line to prevent moisture from entering the vacuum pump.

METHODS

Surface Area

Surface Area by Sor and Kemper's Method. Surface area is estimated from the weight of ethylene glycol retained in a

---

[1] Apiezon hard wax W, purchased from James G. Briddle Co., 1316 Arch Street, Philadelphia 7, Pennsylvania.

[2] Dow Corning high vacuum grease. A silicon lubricant made by Dow Corning Corporation, Midland, Michigan.

monolayer on hydrateable soil surfaces in Sor and Kemper's method (33). Two samples are required for each surface area determination. Each sample is dried over P_2O_5, one sample is saturated with ethylene glycol, then both samples are placed in a vacuum desiccator over an ethylene glycol-bentonite buffer mixture, the desiccator is evacuated and set aside until equilibrium is attained. At equilibrium, the average amount of ethylene glycol retained by the two samples is assumed to represent a monolayer of adsorbed ethylene glycol. Equilibrium is judged to be attained when the sample originally saturated with ethylene glycol retains less than 25 percent more adsorbed ethylene glycol than the sample originally dry.

Amounts of ethylene glycol required to form a monolayer on bentonite hydrateable surfaces was determined to be 0.25 grams ethylene glycol per gram clay by Bower and Gschwend's method (8). This amount of ethylene glycol was added to 400 grams of clay to form the buffer mixture. The buffer mixture is used to maintain the ethylene glycol vapor pressure within the evacuated desiccator at a level corresponding to that of an adsorbed monolayer.

Surface Area by the Proposed Method. The method proposed in this thesis was adapted from Sor and Kemper's method. Time required to reach equilibrium in Sor and Kemper's method is long because of the large excess of ethylene glycol added to one of the two samples required for each determination. In the proposed method the sample is placed in an evacuated desiccator and adsorbs more ethylene glycol than is required for monolayer

formation from a source of free ethylene glycol. The sample is then placed over a buffer as in Sor and Kemper's method, and evacuated until equilibrium is obtained and just a monolayer of ethylene glycol is retained. Determination time for the proposed method is short because little excess glycol is adsorbed and only one sample is required for each surface area determination. Details of the procedure follow: Pass the soil sample through a 60-mesh sieve. Weigh a 0.5 gram sample for each surface area determination in small aluminum moisture cans. Place the cans in a vacuum desiccator over P_2O_5 and evacuate to less than 2 mm. Hg pressure for five to six hours to dry the samples. Weigh the dry samples to the nearest tenth of a milligram.

The surface area of 16 samples was determined in each run using 14 soil and 2 bentonite samples. Place up to 16 dry samples in a vacuum desiccator containing free ethylene glycol and evacuate to less than 2 mm. Hg pressure. Allow the dry samples to adsorb free ethylene glycol for 24 hours. Remove the samples from this desiccator and place over an ethylene glycol-bentonite buffer mixture mixed according to directions by Sor and Kemper. Evacuate the desiccator to less than 2 mm. Hg pressure and allow eight hours to attain equilibrium. Introduce dry air into the desiccator, remove the samples, and weigh to the nearest tenth of a milligram. Bentonite check samples may be used to determine if the samples have reached equilibrium with the buffer.

The amount of ethylene glycol retained per gram is used to calculate surface area. According to Dyal and Hendricks (16),

each soil or clay retains 0.00031 grams of ethylene glycol per square meter of hydrateable surface. This value is used to determine specific surface area with units square meters per gram soil.

Particle Size Analysis

Particle size analysis was determined by Bouyoucos hydrometer method (7). Soils used for this study were fine and medium textured soils, therefore soil equivalent to 50 grams of oven dry soil was used in the analysis. Soils were in an air dry condition and allowance for the moisture percent was made when the soils were weighed for mechanical analysis. Preliminary analysis showed that air dry samples averaged about 2 percent moisture, so 51 grams of air dry soil was used in each determination.

The hydrometer used was calibrated at 67° F. and suspension temperatures were kept at 71° F. $\pm$ 2° F. After the two-hour reading, the suspensions in selected settling cylinders were passed through 300-mesh sieves. The sand particles retained on the sieves were oven-dried, weighed, and percent sand determined. Percent sand determined by sieving was compared to percent sand calculated from the Bouyoucos hydrometer method.

Moisture at Four Tension Levels

The pressure plate apparatus (Richards, 29) was used to determine amounts of soil moisture retained at 1/3 and 1.0

atmospheres tension. The pressure membrane described by Richards (27, 28) was used to determine amounts of soil moisture retained at tensions of 4.0 and 15 atmospheres. Cellulose (Visking) membrane was used to maintain the pressure differential for moisture determinations with the pressure membrane.

Organic Matter

Surface area was determined on both natural and H_2O_2 treated soil. Hydrogen peroxide, 30 percent technical grade, was used to remove organic matter from 3-gram soil samples. Hydrogen peroxide was added to the sample and heated. Organic matter was judged to be removed when effervescence ceased. The soil was passed through 60-mesh sieves and stored in aluminum moisture cans.

Percent organic matter was determined on both natural and H_2O_2 treated soil by the Walkley-Black method, outlined in Jackson (20), 1958:219-221, for each horizon where sufficient sample remained for analysis.

Calculations

Percent moisture retained at various tensions was calculated as follows:

$$\text{Percent water retained} = \frac{\text{grams water} \times 100}{\text{grams oven dry soil}}$$

Specific surface area, square meters surface per gram soil, was calculated on the basis of the soil dried over P_2O_5.

The calculation was as follows:

$$\text{Surface area, m.}^2\text{/gm. soil} = \frac{\text{gm. ethylene glycol retained/gm. soil}}{\text{0.00031 gm. ethylene glycol retained/m.}^2 \text{ of surface.}}$$

Statistical Methods

Statistical analyses were performed according to methods described by Snedecor (34). Regression analyses, confidence limits, correlation coefficients, efficiencies of the prediction equation, and the tests of significance were computed as described by Snedecor. Multiple regression analyses, using three variables, were used to relate moisture retained at 1/3, 1.0, 4.0, and 15 atmospheres tension and surface area to the soil variables sand, silt, clay, and organic matter. Methods for these analyses are given by Snedecor.

Multiple regression analyses were determined, using four and five variables, by the Statistics laboratory at Kansas State University. The analyses were used to relate percent water retained at 1/3 or 15 atmospheres tension to sand, silt, clay, and organic matter.

The regression equation was needed to estimate water retention and surface area. The regression equation is of the form:

$$\hat{Y} = a + bX$$

where $\hat{Y}$ is the best estimate of a variate, a is the y intercept, b is the slope of the regression line, and X is the independent variate.

The closeness of association between two or more variates is measured by means of their correlation coefficient (r). The correlation coefficient lies between the limits +1 and -1 (Finney, 17). If points lie perfectly on a line with a positive or negative slope, r would be +1 or -1, respectively.

From some points of view, r^2 is more a measure of the closeness of association than r. The value r^2 is the efficiency of the prediction equation, and is essentially the proportion of the total variability in one variate that can be accounted for by variations in the other variate or variates. For example, if the correlation coefficient for the comparison between percent clay and surface area is 0.90, the efficiency of the prediction equation (r^2) is 0.81. Therefore, 81 percent of the variation in surface area can be explained as being completely associated with percent clay whereas 19 percent is residual variation independent of percent clay.

RESULTS AND DISCUSSION

Chemical Analyses

Chemical analyses for the 12 soils used in this study were performed by Dixon (15) and Naddih (25). Soil saturation percentage, electrical conductivity, exchange capacity, and pH are found in Table 8 (Appendix). Sites 11a and 11b, "Spearville silty clay loam"; and 12a', Bayard clay loam, each contained horizons with electrical conductivities exceeding 2.0 millimhos per centimeter. Excess salt in these horizons was removed by

dialysis before determining particle size by the Bouyoucos hydrometer method. Cation exchange capacities of the 12 soils ranged from 18.00 to 38.70 m.e./100 gm. soil. Soil pH ranged from 6.4 to 8.4. Only 2 of the 69 horizons present in the soils were acid.

Surface Area

Method Comparison. Surface area values determined by Sor and Kemper and by the proposed method are found in Table 10 (Appendix). Surface area was determined on natural and H_2O_2 treated soil. Percent organic matter present in each soil horizon is also reported in Table 10.

Agreement between methods for surface area determinations was good. Maximum variation between natural soil samples was 23.3 square meters per gram with an average variation of less than 0.2 square meters per gram. Maximum variation in surface area for H_2O_2 treated samples was less than 21.3 square meters of surface per gram with an average variation of less than 2.0 square meters per gram. Errors in the determinations were kept to a minimum by careful weighing, soil sampling, and control of amounts of ethylene glycol adsorbed by the buffer mixtures at equilibrium.

Natural soil samples exposed 212.38 square meters of surface area per gram soil on the average. The H_2O_2 treated soil exposed 198.1 square meters of surface per gram soil on the average. The average difference in surface area resulting from the use of

the two methods was less than 0.07 percent for natural soil and less than 1.0 percent for H_2O_2 treated soil.

Surface area values of natural soil determined by the two methods were compared statistically. The correlation coefficient was 0.988. Figure 1 shows the two sets of surface area values plotted against percent clay. Surface area values obtained for individual samples can be compared by noting the position of vertical pairs of points.

Organic Matter Effect. Using the results from both methods of determining surface area, specific surface area was reduced by an average of 14.15 square meters while organic matter was reduced by an average of .0079 gm. per gram of sample by H_2O_2 treatment (Table 10, Appendix). Each gram of organic matter removed represented 1791 square meters of surface on the average. This is more than double the specific surface of montmorillonite. Bower and Gschwend (8) found that organic matter in soils exposed 700 square meters of surface per gram of organic matter removed. The value determined in this study is more than twofold higher.

Percentage organic matter removed by H_2O_2 treatment varied from 0.29 to 2.28 with an average of 1.03 percent. After organic matter removal by H_2O_2 treatment, percentage organic matter varied from 0.1 to 0.57 with an average of 0.24. Surface horizons originally contained more organic matter than subsurface horizons. Reductions in specific surface area due to organic matter removal were greatest at the surface and generally

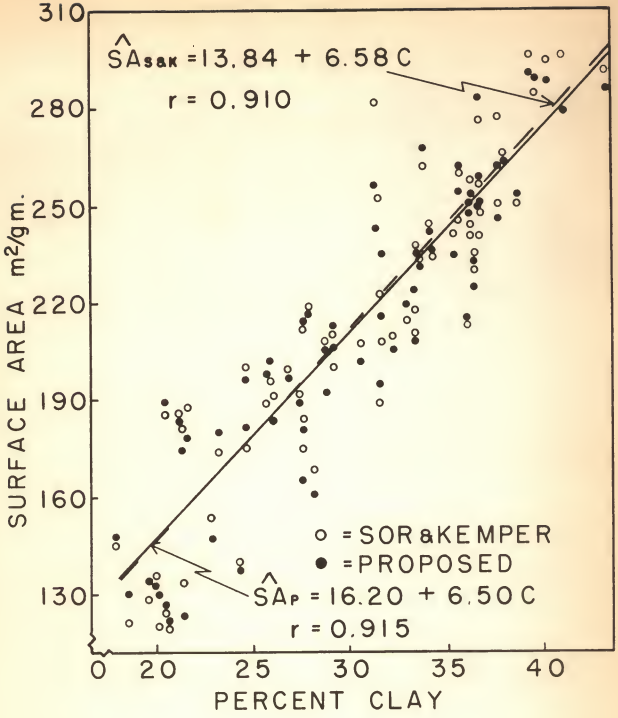

Fig. 1. A comparison of surface area in natural soil as determined by the proposed method, SA_p; Sor and Kemper's method, $SA_{s\&k}$; and percent clay, C. Determinations by the two methods for an individual sample can be compared by noting the position of vertical pairs of points.

decreased with depth. Average reduction in surface area determined by the two methods due to H_2O_2 treatment for the surface horizon of site 42, "Harney silt loam," was 75.3 square meters per gram soil. The soil sample from site 29; a Richfield clay loam, 5 to 13 inches from the surface; contained 1.27 percent organic matter. Surface area determined by the two methods was reduced on an average of 82.3 square meters per gram soil by H_2O_2 treatment. The reason for such large decreases in specific surface area in these two horizons cannot be attributed solely to organic matter removal due to H_2O_2 treatment. The amount of organic matter removed averaged about 1.4 percent for the two horizons. Assuming one gram organic matter exposes 1791 square meters of surface, organic matter removal accounts for an average surface area reduction of only 25.0 square meters per gram soil in the two samples.

Surface area reductions due to H_2O_2 treatment for surface and subsurface horizons at 5-foot depths averaged 15.5 and 5.3 square meters per gram, respectively. Organic matter in surface and in subsurface horizons at a five-foot depth was reduced 1.52 and 0.28 percent, respectively by the H_2O_2 treatment. Assuming that reductions in surface area are due entirely to organic matter removed, the organic matter at the two depths exposed 1020 and 1893 square meters of surface per gram of organic matter removed, respectively. Decomposition of subsurface organic matter is more advanced than that of surface organic matter and would be expected to have a higher specific surface area than surface organic matter.

Use of Proposed Method. The amount of ethylene glycol required to form one monolayer on hydrateable bentonite surfaces was determined by Bower and Gschwend's method. Bentonite retained 0.250 grams of ethylene glycol per gram of clay. Therefore, ethylene glycol-bentonite buffers were prepared to contain 0.250 grams of ethylene glycol per gram of clay at equilibrium.

Using the proposed method, surface area was determined for 14 soil and 2 bentonite samples at one time. Each sample contained an excess of ethylene glycol when placed over the buffer mixture. Free ethylene glycol removed from samples during desiccation is adsorbed, in part, by the buffer. In preparing buffer mixtures, less than 0.250 gram of ethylene glycol is added per gram of bentonite to compensate for the extra ethylene glycol present on the samples.

Buffers used for the proposed method contained 97.5 grams of ethylene glycol and 400 grams of bentonite prior to placement in the desiccator. Such a buffer contains 0.244 gram of ethylene glycol per gram bentonite. The 16 samples usually contain 1.5 to 2.0 grams of ethylene glycol in excess. Excess ethylene glycol from the samples is adsorbed by the buffer during the equilibration process, and the buffer retains 0.247 to 0.248 gram ethylene glycol per gram bentonite at equilibrium. Ethylene glycol adsorbed by the buffer during a second set of determinations would increase the amount of ethylene glycol to 0.251 or 0.254 gram per gram of clay. If the buffer is used for two sets of determinations, differences in amounts of ethylene glycol

retained per gram of clay at equilibrium will be less than 5 milligrams or less than 2 percent. Sor and Kemper (33) concluded that differences this small are negligible.

Figure 2 shows the pattern that is followed as: (a) bentonite and the B_{21} horizon of "Harney clay loam" adsorbs ethylene glycol from a free ethylene glycol source in an evacuated desiccator, and as (b) the rate of ethylene glycol adsorbed decreases with time until the rate of increase ceases. The plateau was established for bentonite and soil after 42 and 30 hours of desiccation, respectively.

Figure 3 shows the pattern that is followed as: (a) bentonite and the A_p horizon of Kieth clay loam adsorbs ethylene glycol from a free ethylene glycol source in an evacuated desiccator, and as (b) the excess is removed by placing the samples over the buffer to equilibrate at less than 2 mm. Hg pressure. Ethylene glycol adsorbed in excess of that required for the formation of the monolayer during the adsorption process was twofold for the soil and less than twofold for the bentonite sample. The time required to reach equilibrium with the buffer is less than 12 hours. Excess ethylene glycol added to samples in the Sor and Kemper method may amount to 10 to 20 times that required for the monolayer, and equilibration time is much longer.

Use of Sor and Kemper's Method. Increases in ethylene glycol retention by the buffer also occurs when Sor and Kemper's method is used. In this method, six soil and two bentonite samples were used for one set of determinations. Since 1 ml. of

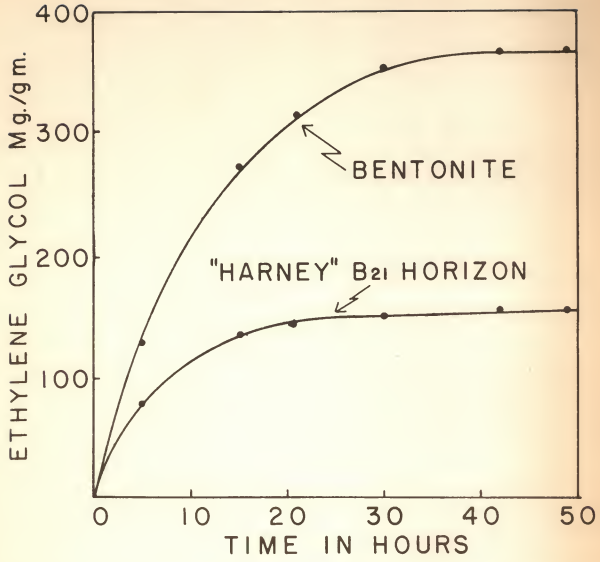

Fig. 2. Adsorption of ethylene glycol from free ethylene glycol by bentonite and the B_{21} horizon of "Harney clay loam".

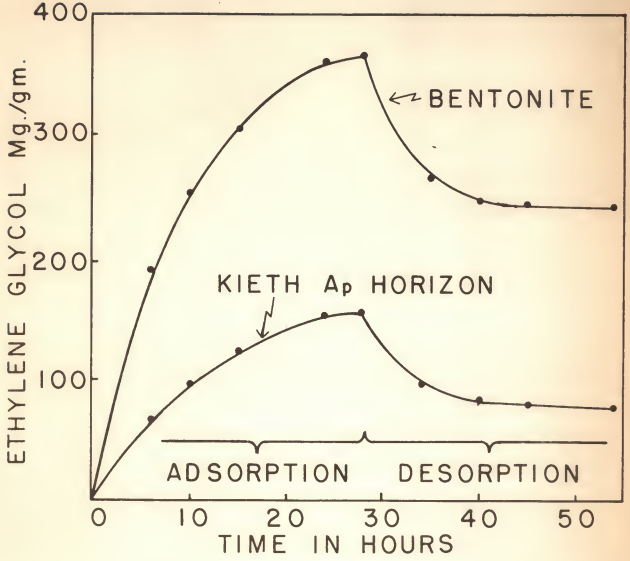

Fig. 3. Adsorption of ethylene glycol from a free ethylene glycol source by bentonite and the A_p horizon of Kieth clay loam, and the desorption of ethylene glycol over a bentonite-buffer mixture.

ethylene glycol was added to four of the eight samples, the excess ethylene glycol on the wetted samples usually amounted to 3.4 to 4.0 grams. Only about 0.5 gram ethylene glycol is adsorbed by dry soil and bentonite samples at equilibrium, leaving 3.0 to 3.5 grams of ethylene glycol in excess. To compensate for this excess, the buffer mixture is prepared to contain only 0.240 gram of ethylene glycol per gram of clay. Buffer mixtures used for Sor and Kemper's method contained 96 grams of ethylene glycol and 400 grams of clay. The remaining 3.0 to 3.5 grams excess ethylene glycol is adsorbed by the buffer, and 0.248 to 0.249 gram ethylene glycol per gram of clay is retained at equilibrium. Vapor pressure of ethylene glycol adsorbed on the buffer and sample surfaces will be equal at equilibrium, and theoretically, a monolayer of ethylene glycol will be retained on each exposed hydrateable surface.

Specific surface area of four soil samples was determined in a single run by Sor and Kemper's method. One sample was originally saturated with ethylene glycol and lost ethylene glycol during the evacuation process. The other sample was originally dry and gained ethylene glycol during evacuation. Specific surface area was determined from the average weight of ethylene glycol retained by two samples of a single soil.

Eight grams of dry bentonite was mixed with the buffer after being used for four surface area determinations by Sor and Kemper's method. The desiccator containing the buffer mixture was evacuated to less than 2 mm. Hg pressure for 24 hours.

Under these conditions, two assumptions were made: (a) ethylene glycol became uniformly distributed on bentonite surfaces, and (b) bentonite retained 0.245 gram ethylene glycol per gram clay. Four additional surface area determinations were made and the buffer discarded.

Comparison of Proposed and Sor and Kemper's Method for Specific Surface Area. Sixteen samples were used for one set of determinations by the proposed method. The proposed method requires less than 36 hours for one set of determinations. This time includes a 24-hour period during which samples are allowed to adsorb ethylene glycol in an evacuated desiccator containing free ethylene glycol, and the 12-hour period for equilibration. Sor and Kemper's method requires 72 hours to make one set of determinations. A minimum of 48 hours is required for samples to reach equilibrium in this method because of the large excess of ethylene glycol present.

The proposed method for making surface area determinations is more rapid than Sor and Kemper's method. Four times the number of determinations are made for one run, and equilibrium is established in approximately one-half the time; consequently, the method is about eight times more rapid than Sor and Kemper's method.

One buffer mixture may be used for two sets of surface area determinations for both methods. In two runs, surface area can be determined for 32 samples by the proposed method and for 8 samples by Sor and Kemper's method. Four buffer mixtures are

required for 32 surface area determinations by Sor and Kemper's method. One buffer mixture is required for the same number of surface area analyses by the proposed method. Two samples are required per specific surface area determination by Sor and Kemper's method. Only one sample is required for each determination by the proposed method. Weighing time per determination for the proposed method is just half that required by Sor and Kemper's method. The proposed method, therefore, conserves both time and labor.

Surface Area of Size Fractionated Bentonite

Wyoming bentonite, the clay standard used in this study, was analyzed to determine percentages of various sized fractions in natural bentonite and surface area of each size range separated. Bentonite was separated into size ranges as follows: greater than 2.0 microns, 2.0 to 0.2 microns, 0.2 to 0.08 micron, and $<$0.08 micron.

Fractionation Procedure. The procedure used for fractionation follows. Disperse a 19.90 gm. Wyoming bentonite sample in 1 liter of water. Separate the clay particles $>$2.0 microns by sedimentation with size 1, type MA and ME International centrifuge operated at 750 r.p.m. for 2.5 minutes.[3] Decant, then disperse the sediment with water and re-centrifuge. Combine the decantates and repeat the washing six times. Dry the sediment at 110° C.

Use a supercentrifuge to separate the 2.0 to 0.2 micron clay particles. Pass the combined decantates from above through

[3] Manufactured by International Equipment Co., Boston, Mass.

supercentrifuge at the rate of 415 ml. per minute as recommended by Jackson (19). Transfer sediment to a 1 liter beaker and dry at 110° C. Pass remaining solution through the supercentrifuge at the rate of 60 ml. per minute to separate the 0.2 to 0.08 micron bentonite. Repeat transfer procedure and dry at 110° C. Oven dry solution containing <0.08 micron bentonite at 110° C. Shake intermittently during evaporation period to prevent small amounts of <0.08 micron bentonite from collecting on the container walls. Transfer the last 2 liters of suspension to 1-liter beakers and oven dry contents at 110° C. Transfer contents of beakers containing the various size fractions to aluminum moisture cans. The weight and percentages are determined for each size fraction. Results are reported in Table 1.

The >2.0 micron fraction makes up 15.2 percent of natural bentonite. This amount is larger than that noted by other investigators. Sor and Kemper (33) reported commercial grade of Wyoming bentonite used for their study contained about 6 percent impurities.

Surface Area by Sor and Kemper's Method. Samples were ground to a fine powder with an automatic mortar and pestle. Samples were passed through a 100-mesh sieve. Samples of each size range were saturated with excess ethylene glycol and set aside for 16 days. Surface area of each size fraction was determined by Sor and Kemper's method. Results are reported in Table 1. The results indicate some clay plates were "stuck together" irreversibly. The greater than 2.0 micron fraction had a

Table 1. Percentage, weight, d-spacing, surface area, and minerals present in each of the 2.0, 2.0 to 0.2, 0.2 to 0.08, and 0.08 micron size fractions in Wyoming bentonite.

Size fraction	Weight		Surface area	d-spacing[1]	
micron	gm.	%	$m.^2/gm.$	A	Mineral
2.0	3.05	15.2	82.0	20.380	Bentonite
				16.866	Bentonite
				10.081	Illite or Mica
				6.435	Feldspar
				4.279	Gypsum[2]
				4.056	Feldspar
				3.772	Feldspar
				3.360	Quartz
				2.453	Quartz
				2.283	Quartz
				2.237	Quartz
				1.981	Quartz
				1.820	Quartz
				1.672	Quartz
2.0-0.2	10.22	51.3	490.8	20.797	Bentonite
				10.062	Illite or Mica
				3.345	Quartz
				2.550	Quartz
				1.814	Quartz
				1.533	Quartz
				1.489	Bentonite
				1.370	Bentonite
0.2-0.08	2.88	14.5	900.1	20.624	Bentonite
				4.500	Bentonite
				2.571	Bentonite
				1.493	Bentonite
				1.294	Bentonite
				1.241	Bentonite
0.08	3.59	18.0	670.0	20.588	Bentonite
				4.481	Bentonite
				2.555	Bentonite
				1.686	Bentonite
				1.493	Bentonite
				1.289	Bentonite
				1.247	Bentonite
Weighted mean			515.5		

[1] The d-spacing from X-ray film.

[2] The identification of this mineral is questionable.

specific surface area of 82.0 square meters per gram. The 2.0 to 0.2 micron clay retained 0.152 gram ethylene glycol per gram clay and the specific surface area was 490.8 square meters per gram. The 0.2 to 0.08 micron clay retained 0.279 gram ethylene glycol per gram clay. Surface area was 900.1 square meters per gram. Less than 0.08 micron clay retained 0.208 gram ethylene glycol for 670 square meters specific surface per gram clay. Surface area determined for bentonite, in its natural condition, was 808.6 square meters per gram.

The products of specific surface for each size fraction and their percentages were summed to obtain a weighted surface area value. The weighted surface area for the fractionated bentonite was 515.5 square meters per gram. The fractionation procedure reduced bentonite specific surface area by 293.1 square meters per gram.

X-ray of Bentonite. A Norelco X-ray powder machine was used to X-ray water-wetted bentonite samples.[4] Cobalt K alpha radiation was used. The handbook "Tables for Conversion of X-ray Diffraction Angles to Interplanar Spacing" was used to convert angle to d-spacing.[5] Minerals present with bentonite were identified from d-spacing as outlined by Brindley (11).

---

[4] Manufactured by North American Philip Co., Inc., Mount Vernon, New York.

[5] Published by United States Government Printing Office, Washington 25, D.C. Natural Bureau of Standards Applied Mathematics Series 10, 1950.

Wet bentonite d-spacings were measured as shown by X-ray films by a Film Illuminator and Measuring Device.[6] The d-spacings and minerals identified from X-ray film for each size range are reported in Table 1.

The greater than 2.0 micron fraction contains impurities of various minerals. These minerals were identified as Illite or Micas, Feldspars, Gypsum, and Quartz in the > 2.0 micron fraction. Quartz was present in 2.0 to 0.2 micron clay. Only bentonite was present in the 0.2 to 0.08 and < 0.08 micron fractions of bentonite.

Soil Texture

Soil class names determined by mechanical analysis (M.A.) and Soil Conservation Service technicians, using "Feel Methods" for each horizon in 12 soil sites, are found in Table 10. Individual sand, silt, and clay percentages are also reported. Checks upon sand content of selected horizons were made by passing the soil suspension used in mechanical analysis through a 300-mesh sieve. These results are listed in Table 10.

The sand particles retained on the 300-mesh sieve were dried, weighed, and percentage sand calculated. Percent sand, determined by sieving, agreed closely with percent sand determined by mechanical analysis. Percent sand determined by mechanical analysis varied from 2.4 percent more to 1 percent

---

[6] Manufactured by North American Philip Co., Inc., Mount Vernon, New York.

less than sand retained on the 300-mesh sieve. Percent sand, determined by mechanical analysis, averaged 1 percent higher than that determined by sieving.

The number of horizons corresponding to each soil class determined for 69 horizons in 12 soil sites by mechanical analysis and Soil Conservation Service technicians are reported in Table 2. Twenty-four of the 46 horizons described by Soil Conservation Service technicians as silty clay loams were found to be clay loams by mechanical analysis. The 24 horizons which underwent the classification change ranged in percent sand from 20.2 to 28.3, and averaged 23.3 percent. Five other silty clay loam horizons underwent classification changes. Two of the horizons were finally classed as loams, two as silt loams, and one as clay after mechanical analysis. Soil Conservation Service technicians classed five horizons as loams but by mechanical analysis, 13 horizons were found to be loams. The greatest area of disagreement between the classification by mechanical analysis and the judgment of the technicians was between the clay loam and silty clay loam classification.

Percent Clay and Surface Area. Percent clay and surface area was determined for each of the 69 horizons present in the 12 sites. The regression relationship between percent clay and surface area of natural soil determined by the proposed and Sor and Kemper's method is shown in Figs. 4 and 5, respectively. Surface area increases as percent clay increases, and the two methods give nearly identical results. The regression equations

Table 2. Comparison of soil class names determined for 69 horizons in 12 soil sites by mechanical analysis (M.A.) and by Soil Conservation Service technicians using "Feel Methods."

Soil class by horizon	No. of horizons	
	"Feel Methods"	(M.A.)
Clay	0	1
Silty clay	4	2
Clay loam	6	28
Silty clay loam	46	17
Silt loam	8	8
Loam	5	13

for the two methods follow:

$$\hat{SA}_p = 16.20 + 6.50C \qquad (1)$$

where $\hat{SA}_p$ is surface area of natural soil determined by the proposed method and C is percent clay.

$$\hat{SA}_{sk} = 13.90 + 6.58C \qquad (2)$$

where $\hat{SA}_{sk}$ is surface area of natural soil determined by Sor and Kemper's method.

Surface area predicted by the two regression equations varied less than 2.0 square meters per gram at the high and the low clay percentages. Unit increases in percentage clay increased surface area by 6.58 and 6.50 square meters per gram for Sor and Kemper's and the proposed method, respectively. Tolerance limits at the 0.05 level were calculated for each of

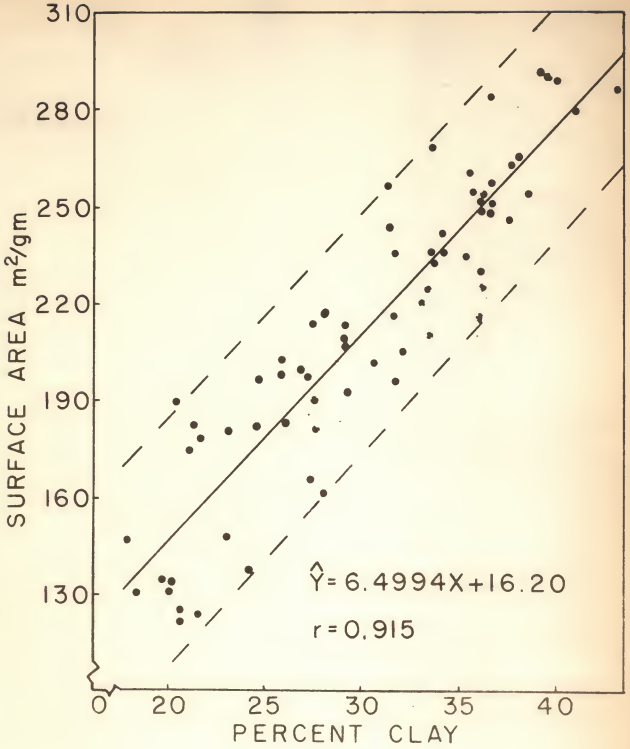

Fig. 4. Relationship between surface area of natural soil determined by the proposed method and percent clay.

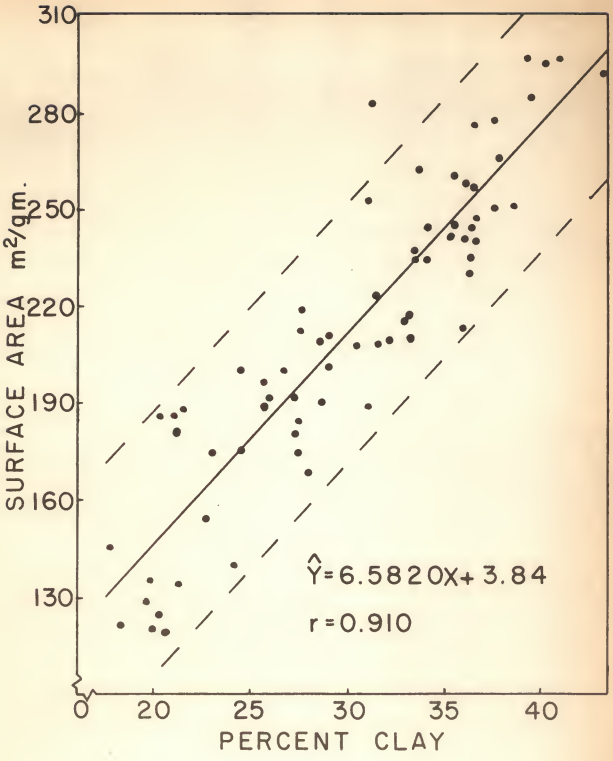

Fig. 5. Relationship between surface area in natural soil determined by Sor and Kemper's method and percent clay.

the relationships and appear as the dashed lines in Figs. 4 and 5. In the range of clay content encountered in these soils, surface area could be predicted at the 0.05 level of probability within ± 38.5 and ± 40.5 square meters per gram for the proposed and Sor and Kemper's method, respectively.

Percent Sand, Silt, or Clay with Surface Area. Percent silt and sand was compared to surface area of natural soil determined by the proposed and Sor and Kemper's method. Percent clay was compared to surface area of both natural and H_2O_2 treated soil determined by the two methods. These comparisons were made to determine which soil fraction could be used with greatest efficiency to predict surface area.

Correlation coefficients for these comparisons are reported in Table 3. The t-test was used to test for significance, and the results for each comparison are indicated in Table 3. Correlation coefficients for the comparisons percent clay vs. specific surface area of natural soil determined by the proposed and Sor and Kemper's method were 0.915 and 0.910, respectively. Correlation coefficients for percent clay vs. surface area of H_2O_2 treated soil was 0.864 for the proposed method and 0.860 for Sor and Kemper's method. These results reflect the importance of clay content in determining specific surface area of soils. The linear nature of the relationship between clay content and surface area of natural soil is shown in Figs. 4 and 5.

Removal of organic matter by H_2O_2 treatment reduced both specific surface area of the soils and the correlation between

Table 3. Correlation coefficients for various comparisons between clay, silt, and sand with surface area of natural and H_2O_2 treated soil determined by two methods.

No.	Treatment	Comparison	Method: Proposed r[1]	Method: Sor & Kemper r
1	Natural	Clay vs. surface area	0.915***	0.910***
2	H_2O_2	Clay vs. surface area	0.863***	0.860***
3	Natural	Silt vs. surface area	-0.199 ns	-0.184 ns
4	Natural	Sand vs. surface area	-0.708***	-0.715***

[1] Correlation coefficient.
*** Significant at the 0.001 level.
ns Non-significant at the 0.05 level.

percent clay and surface area. No explanation can be offered for the reduction in correlation due to H_2O_2 treatment. Predicted surface area will be more accurate if natural soil is used for the determination.

Correlation coefficients for the comparisons, percent sand vs. surface area of natural soil determined by the proposed and Sor and Kemper's method, were -0.708 and -0.715, respectively. The slopes of the regression lines relating these variables are negative. Each increase in percent sand resulted in decreased surface area.

Correlation coefficients recorded in Table 3 show there was no significant relationship between percent silt and surface area.

Comparisons Between Percent Sand, Silt, Clay, and Organic Matter. Percent clay, silt, and sand are interrelated because one of these components cannot be changed without altering the proportion of one or both of the other components. Data in Table 4 indicate the relationships between percent clay and silt, percent clay and sand, percent silt and sand, and percent sand, silt, and clay with organic matter. The regression equations for the significant comparisons are given below:

$$\hat{Si} = 54.54 + -0.303C \quad (3)$$

where $\hat{Si}$ is percent silt.

$$\hat{S} = 45.09 + -0.69C \quad (4)$$

where $\hat{S}$ is percent sand.

$$\hat{S} = 49.40 + -0.553\ Si \quad (5)$$

Table 4. Correlation coefficients for various comparisons between clay, silt, sand, and organic matter in natural soil.

No.	Comparison	Correlation coefficient r
1	Clay vs. organic matter	-0.084 ns
2	Clay vs. silt	-0.354***
3	Clay vs. sand	-0.657***
4	Silt vs. organic matter	-0.078 ns
5	Silt vs. sand	-0.449***
6	Sand vs. organic matter	-0.168 ns

*** Significant at 0.001 level.
ns Non-significant at 0.05 level.

The equations show that with unit increase in percent clay, sand decreased by 0.69 percent and silt decreased by 0.303 percent. Unit increase in percent silt resulted in a 0.553 percent decrease in percent sand. Surface area decreased as percent clay decreased as was previously indicated by the positive relationships between these variables. The sand content of these soils increase sharply as percent clay decreases, and nearly as rapidly when percent silt decreases. This partially accounts for the significant relationships between sand and surface area.

Table 4 indicates no significant relationship between percent clay, silt, or sand vs. organic matter.

Moisture Retention at Four Tension Levels

The pressure plate apparatus was used to determine moisture retained by the soil at 1/3 and 1.0 atmosphere tension. The pressure membrane was used to determine amount of water retained at 4.0 and 15 atmospheres tension.

Moisture retained at these four tensions and range of available water determined by horizon in 12 soil sites is reported in Table 12 (Appendix).

Percent water retained by soils at 1/3 and 15 atmospheres tension were considered to represent field capacity and permanent wilt point, respectively. Tension variations near 15 atmospheres take place without greatly affecting amounts of moisture retained. Soil moisture tension and percentage clay appear to play a major role in determining amount of water retained by soil.

Percent Clay and Moisture Retention. Moisture retained at 1/3, 1.0, 4.0, and 15 atmospheres tension for the 69 horizons was plotted against percent clay. The regression relationships and correlation coefficients are shown in Figs. 6 to 8. Confidence limits, at the 95 percent level, were placed on the individual observations and appear as dashed lines in each of the figures. The confidence limits were essentially linear and parallel to the regression line over the range in percentage clay encountered in these soils. Confidence limits were placed $\pm$ 7.0, $\pm$ 4.6, $\pm$ 3.1, and $\pm$ 2.6 percentage units from the regression lines for 1/3, 1.0, 4.0, and 15 atmospheres tension, respectively. As tension increased from 1/3 to 15 atmospheres, the range between confidence limits narrowed. Correlation coefficients normally increase as the range between confidence limits decreases. The correlation coefficient for the comparison percent clay vs. percent water retained at 4.0 atmospheres was 0.930, and larger than the correlation coefficient for the comparison percent clay and percent water retained at 15 atmospheres tension, which was 0.928.

The correlation coefficients and prediction efficiencies for relationships between percent sand, silt, clay, or organic matter to moisture retained at 1/3, 1.0, 4.0, or 15 atmospheres tension, or range of available water are reported in Table 5.

Correlation coefficients for comparisons percent clay vs. percent water and percent sand vs. percent water retained at 1/3 atmosphere tension was 0.837 and -0.853, respectively.

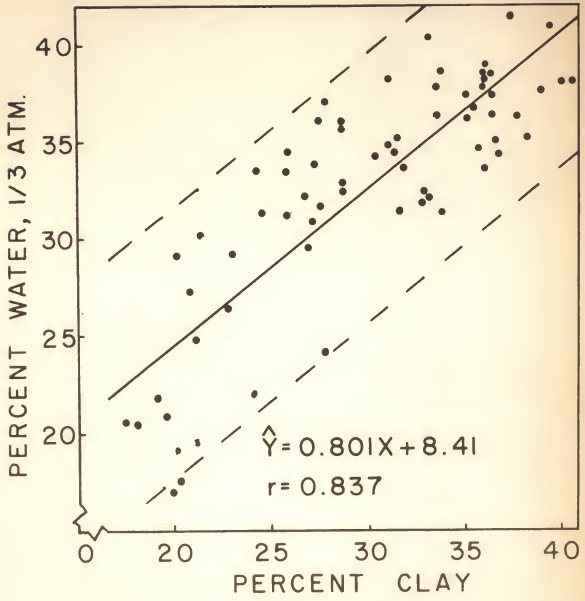

Fig. 6. Relationship between percent water retained at a tension of 1/3 atmosphere and percent clay.

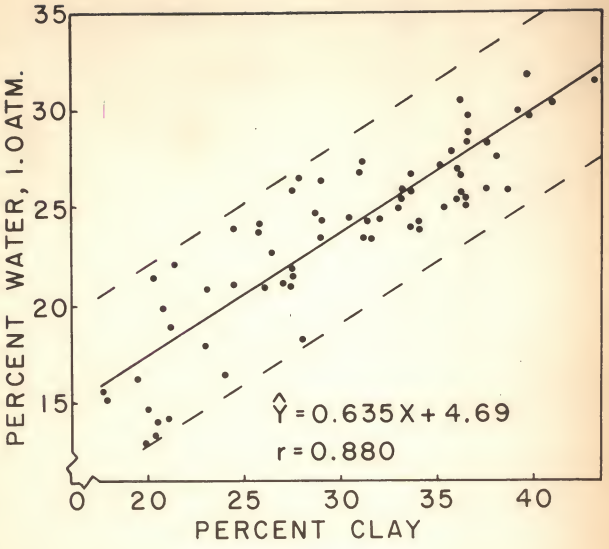

Fig. 7. Relationship between percent water retained at a tension of 1.0 atmosphere and percent clay.

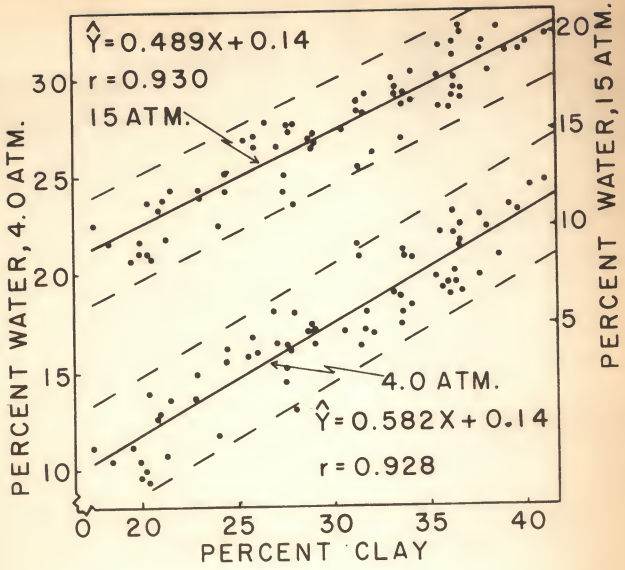

Fig. 8. Relationship between percent water retained at a tension of 4.0 and 15 atmospheres and percent clay.

Table 5. Correlation coefficients and prediction efficiencies for comparisons between clay, silt, sand, or organic matter, and moisture retained at 1/3, 1.0, 4.0, or 15 atmospheres tension, or range of available water.

No.	Comparison	Correlation coefficient r	Prediction efficiency[1] %
1	Clay vs. water retained at 1/3 atm. tension	0.837***	70.10
2	Clay vs. water retained at 1.0 atm. tension	0.880***	77.46
3	Clay vs. water retained at 4.0 atm. tension	0.930***	86.55
4	Clay vs. water retained at 15 atm. tension	0.928***	86.14
5	Clay vs. range of available water	0.537***	28.83
6	Silt vs. water retained at 1/3 atm. tension	0.055 ns	0.31
7	Silt vs. water retained at 15 atm. tension	-0.194 ns	3.75
8	Silt vs. range of available water	0.278*	7.74
9	Sand vs. water retained at 1/3 atm. tension	-0.853***	72.71
10	Sand vs. water retained at 15 atm. tension	-0.723***	52.29
11	Organic matter vs. water retained at 1/3 atm.	-0.089 ns	0.80
12	Organic matter vs. water retained at 15 atm.	-0.023 ns	0.19

[1] Prediction efficiency is r^2 x 100 where r is the correlation coefficient.

ns Non-significant at 0.05 level.

* Significant at 0.05 level.

*** Significant at 0.001 level.

The two values are nearly identical; however, percent water retained increased with increasing clay but decreased with increasing sand. At other tensions used, correlation between clay and moisture retention was better than for sand and moisture retention.

The correlation coefficients for relationships between percent clay and water retained at 1/3, 1.0, 4.0, and 15 atmospheres tension were 0.837, 0.880, 0.930, and 0.928, respectively. As tension increased, a larger amount of the total variability included in percent moisture was completely associated with percent clay.

Moisture Retention and Range of Available Water. The amount of water retained for the 69 horizons investigated at a tension of 1/3 atmosphere varied from 16.8 to 44.3 percent as percent clay varied from 17.6 to 43.2 percent, as can be observed in Fig. 6. Percent water retained at tensions of 1.0, 4.0, and 15 atmospheres ranged from 12.8 to 32.0, 9.4 to 24.7, and 8.1 to 20.2 percent, respectively. Moisture retained at 1.0, and 4.0 and 15 atmospheres tension plotted against percent clay is reported in Figs. 7 and 8, respectively.

Range of available water is the percent water retained by soil between tensions of 1/3 and 15 atmospheres or between field capacity and permanent wilt point. The correlation coefficient between range of available water and percent silt was significant at the 0.05 level. The relationship between range of available water and percent clay was significant at the 0.001 level.

Percent clay ranged from 17.6 to 43.2. As percent clay increased, range of available water increased. At 17.6 percent clay, range of available water was 8.4 percent, while at 43.2 percent clay, range of available water was 25.5 percent.

Lund (23) worked with 68 horizons from 22 alluvial Louisiana soil series. Range of available water in these soils was more closely related to silt than to clay which is just the reverse of results found in this study.

Sand, Silt, Organic Matter, and Moisture Retention. Comparisons were made with percent silt and moisture retained at 1/3 and 15 atmospheres tension to determine the effect of silt on water holding capacity of these soils. Correlation coefficients for these comparisons were 0.055 and -0194, respectively, and were non-significant.

Correlation coefficients for the comparisons percent sand vs. percent water retained at 1/3 and 15 atmospheres tension were -0.853 and -0.723, respectively. The correlation coefficients were significant at the 0.001 level. The slopes of the regression lines were negative, consequently, moisture retention of these soils increased as percent sand decreased.

Percent organic matter was compared to percent water retained at tensions of 1/3 and 15 atmospheres. The correlation coefficients for these comparisons were -0.089 and 0.023, respectively and were non-significant. Organic matter adsorbs water on its surfaces, but because it is present in small amounts in soils, it has little effect on total water retained per unit weight of soil.

Relationships Between Surface Area and Moisture Retention

Percent water retained at 1/3, 1.0, 4.0, and 15 atmospheres tension was correlated with surface area of natural and H_2O_2 treated soil as determined by two methods. Correlation coefficients, prediction efficiencies, and tests for significance for these comparisons are reported in Table 6. Since surface area determinations by Sor and Kemper's method and by the proposed method gave close results, only the relationships between moisture retention and surface area determined by the proposed method are discussed below.

Close relationships existed between surface area and moisture retained at each of the four tensions. The correlation coefficient for the comparison, percent water retained at 1/3 atmosphere tension vs. specific surface area of natural soil was 0.887. The regression equation relating these variables is:

$$\hat{P}_w \text{ at } 1/3 \text{ atm.} = 7.22 + 0.120 \text{ SA} \qquad (6)$$

where $\hat{P}_w$ at 1/3 atm. is percent water retained at 1/3 atmosphere tension and SA is specific surface area of natural soil. The regression equation accounts for 78.6 percent of the total variation in percent water that can be explained as being completely associated with percent clay. Percent water retained by soil at 1/3 atmosphere tension was more closely correlated with specific surface area than with percent clay. The correlation coefficient of the latter comparison was 0.837.

Table 6. Correlation coefficients and prediction efficiencies for comparisons between moisture retained at 1/3, 1.0, 4.0, and 15 atmospheres tension and surface area of natural and H_2O_2 treated soil determined by two methods.

No.	Comparison	Correlation coefficient		Prediction efficiency[1]	
		Proposed method	S&K method[2]	Proposed method	S&K method
		r		%	
1	Water at 1/3 atm. vs. surface area	0.887***	0.880***	78.64	77.51
2	Water at 1/3 atm. vs. surface area[3]	0.837***	0.845***	70.70	71.31
3	Water at 1.0 atm. vs. surface area	0.944***	0.942***	89.19	88.77
4	Water at 1.0 atm. vs. surface area[3]	0.918***	0.925***	84.25	85.54
5	Water at 4.0 atm. vs. surface area	0.963***	0.969***	92.80	93.90
6	Water at 4.0 atm. vs. surface area[3]	0.902***	0.906***	81.38	82.08
7	Water at 15 atm. vs. surface area	0.941***	0.935***	88.56	87.37

[1] Prediction efficiency = r^2 x 100 where r is the correlation coefficient.

[2] Sor and Kemper's method.

[3] Surface area of H_2O_2 treated soil.

*** Significant at 0.001 level.

Correlation coefficients for the comparisons, percent water retained at 1.0 and 4.0 atmospheres tension with surface area of natural soil determined by the proposed method, were 0.944 and 0.963, respectively. Hydrogen peroxide treatment prior to

surface area determination reduced the correlation coefficient for the comparisons percent water retained at 1.0 and 4.0 atmospheres tension vs. surface area from 0.944 to 0.918 and from 0.963 to 0.902, respectively.

The correlation coefficient for the comparison percent water retained at 15 atmospheres tension and surface area of natural soil determined by proposed method was 0.941. The regression equation relating these variables is:

$$\hat{P}_w \text{ at 15 atm.} = 0.14 + 0.07\ SA \qquad (7)$$

where $\hat{P}_w$ at 15 atm. is precent water retained at 15 atmospheres tension. There is 88.56 percent of the total variability associated with the two variates. Percent water retained at 15 atmospheres can be predicted better than percent water retained at 1/3 atmosphere tension by using surface area of natural soil as the prediction basis.

Multiple Regression Analysis Using Three, Four, and Five Variables

Previous results have used one variable as the prediction basis to estimate percent water retained at 1/3 and 15 atmospheres tension. Two, three, and four soil variables are used below as the prediction basis to better predict moisture retained at the two tension levels.

Three Variables. Two soil variables were used to predict percent water retained at 1/3 or 15 atmospheres tension.

Correlation coefficients, prediction efficiencies, and tests for significance for comparisons between percent clay and sand, clay and silt, clay and organic matter, sand and surface area of natural soil determined by proposed method with percent water retained at 1/3 or 15 atmospheres tension are reported in Table 7.

Correlation coefficients for comparisons, percent clay and sand vs. percent water retained at 1/3 and 15 atmospheres tension were 0.928 and 0.941, respectively. The regression equations relating these variables are:

$$\hat{P}_w \text{ at } 1/3 \text{ atm.} = 30.08 + 0.466C + -0.477S \quad (8)$$

$$\hat{P}_w \text{ at } 15 \text{ atm.} = 4.80 + 0.415C + -0.100S \quad (9)$$

Regression equations 8 and 9 account for 86.2 and 88.5 percent of the total variability, respectively. The residual variation of percent water retained, independent of clay and sand, was 13.8 and 11.5 percent, respectively for the two comparisons. Percent clay and sand were more closely correlated with percent water retained at 15 atmospheres tension than with percent water retained at 1/3 atmosphere tension.

Correlation coefficients for the comparisons, percent clay and silt vs. percent water retained at 1/3 and 15 atmospheres tension, were 0.917 and 0.940, respectively. It was concluded that clay, in combination with either silt or sand, could be used equally well to predict moisture retention at 1/3 or 15 atmospheres. Using both clay and sand instead of clay alone, in

Table 7. Correlation coefficients and prediction efficiencies for various comparisons between clay, silt, sand, organic matter, or surface area of natural soil determined by proposed method with percent water retained at 1/3 or 15 atmospheres tension.

No.	Comparison	Correlation coefficient: R	Prediction efficiency[1] %
	Five variables		
1	Clay, silt, sand, and organic matter vs. P_w at 1/3 atm.[2]	0.963***	92.72
2	Clay, silt, sand, and organic matter vs. P_w at 15 atm.[3]	0.954***	90.91
	Four variables		
3	Clay, sand, and organic matter vs. P_w at 1/3 atm.	0.930***	86.42
4	Clay, sand, and organic matter vs. P_w at 15 atm.	0.949***	90.11
	Three variables		
5	Clay and silt vs. P_w at 1/3 atm.	0.917***	84.17
6	Clay and silt vs. P_w at 15 atm.	0.940***	88.41
7	Clay and sand vs. P_w at 1/3 atm.	0.928***	86.20
8	Clay and sand vs. P_w at 15 atm.	0.941***	88.54
9	Clay and organic matter vs. P_w at 1/3 atm.	0.868***	75.30
10	Clay and organic matter vs. P_w at 15 atm.	0.944***	89.10
11	Clay and P_w at 1/3 atm. vs. P_w at 15 atm.	0.941***	88.54
12	Sand and surface area vs. P_w at 1/3 atm.[4]	0.951***	90.52

[1] Prediction efficiency is R^2 x 100 where R is the multiple correlation coefficient.

[2] Percent water retained at 1/3 atmosphere tension.

[3] Percent water retained at 15 atmospheres tension.

[4] Surface area of natural soil determined by proposed method.

*** Significant at 0.001 level.

the prediction equation, improved the prediction efficiency approximately 16.1 and 2.4 percent at 1/3 and 15 atmospheres tension, respectively.

Percent clay and organic matter was compared to percent water retained at 1/3 and 15 atmospheres tension. Correlation coefficients were 0.868 and 0.944, respectively. Using both clay and organic matter instead of clay alone, improved the prediction efficiency by 5.2 and 3.0 percent at 1/3 and 15 atmospheres tension, respectively.

The correlation coefficient for the comparison percent clay and percent water retained at 1/3 atmosphere tension to percent water retained at 15 atmospheres tension was 0.941. Prediction of moisture retention at 15 atmospheres tension was not improved by using clay and percent water retained at 1/3 atmosphere tension instead of clay and sand in the regression equation.

Surface area of natural soil determined by the proposed method and sand, was related to percent water retained at 1/3 atmosphere tension. The correlation coefficient was 0.951. The efficiency of the prediction equation was increased 11.8 percent when surface area and sand instead of surface area alone was used to predict percent water retained at 1/3 atmosphere tension.

Four Variables. Percent clay, sand, and organic matter were compared to percent water retained at 1/3 and 15 atmospheres tension. The correlation coefficients were 0.930 and 0.949, respectively. The regression equations relating these variables are:

$\hat{P}_w$ at 1/3 atm. = 29.95 + 0.464C + -0.493S + 0.582 O.M. (10)

where O.M. is percent organic matter.

$\hat{P}_w$ at 15 atm. = 4.14 + 0.417C + -0.112S + 0.865 O.M. (11)

The correlation coefficients for the above comparisons are nearly identical with the correlation coefficients for the comparisons percent clay and sand vs. percent water retained at 1/3 and 15 atmospheres. The correlation coefficients for the latter comparisons were 0.928 and 0.941, respectively.

Regression equations 10 and 11 account for 86.42 and 90.11 percent of the total variation in percent water that is directly associated with percent clay, silt, and organic matter.

For each comparison made, correlation coefficients and prediction efficiencies were larger when three variables were compared to percent water retained at 1/3 or 15 atmospheres tension than when one variable was used.

Five Variables. A quantity like percent moisture can be predicted more efficiently by using as many variables as possible in the regression equation. Four soil factors: percent sand, silt, clay, and organic matter were compared to percent water retained at 1/3 and 15 atmospheres tension. The correlation coefficients for the comparisons were 0.963 and 0.954, respectively. The regression equations relating these variables are:

$\hat{P}_w$ at 1/3 atm. = 247.38 + -1.727C + -2.156 Si
+ -2.730S + 1.379 O.M. (12)

$\hat{P}_w$ at 15 atm. = 45.85 + -0.003C + -0.413 Si
+ -0.542S + 1.030 O.M. (13)

The preceding regression equations account for 92.7 and 90.91 percent of the total variation in percent water that is associated with the four soil variables, respectively.

Percent water retained at 1/3 and 15 atmospheres tension can be predicted with greater efficiency using four instead of three soil variables in the regression equation. Efficiency of the prediction equation increased from 86.42 to 92.7 percent when percent silt was used in addition to percent clay, sand, and organic matter to predict percent water retained at 1/3 atmosphere tension. Prediction efficiencies for comparisons, using three and four variables with percent water retained at 15 atmospheres tension, were 90.11 and 90.91 percent, respectively. Percent silt accounts for 5.5 percent more of the total variability associated with percent water retained at 1/3 atmosphere than with water retained at 15 atmospheres tension.

SUMMARY

The purpose of this study was to relate moisture retention characteristics of six western Kansas soils to surface area and clay content. This study was divided into three parts: (a) the mechanical analysis of soils by the Bouyoucos hydrometer method, (b) moisture retained at 1/3, 1.0, 4.0, and 15 atmospheres tension, and (c) surface area determinations.

Sor and Kemper's method was used initially to estimate total surface areas of soils. Preliminary studies, using Sor and Kemper's method to determine specific surface area of soils,

indicated: (a) a minimum of 72 hours was required to determine surface area on one set of samples, (b) the preparation of the buffer mixtures was time consuming, (c) four surface area determinations were made for each run, and (d) eight determinations were made with each buffer.

A need was realized for an accurate and more rapid method to estimate total hydrateable surfaces of soils. An equilibrium method for determining surface areas of soils was developed. Principles used to develop this method were established by Bower and Gschwend, Dyal and Hendricks, and Sor and Kemper.

One phase of this study was to compare the two methods used to estimate surface areas of soils. The findings were: (a) surface area can be estimated equally well by both methods, (b) a set of surface area determinations using the proposed method can be made in about half the time required for Sor and Kemper's method, (c) fewer buffer mixtures and less preparation time are required for the proposed method, and (d) fourfold more surface area determinations are made in one run, using the proposed method, than can be made using Sor and Kemper's method.

Surface area was determined on natural and H_2O_2 treated soil by both methods. Maximum variation in surface area for natural and H_2O_2 treated soil determined by the proposed and Sor and Kemper's method was 23.3 and 21.3 square meters per gram, respectively. The average difference was 0.2 and 2.0 square meters per gram, respectively.

Surface area was determined on each of four size fractions of Wyoming bentonite. The fractionation procedure reduced the specific surface area from 808.6 to 515.5 square meters per gram. The large reduction was attributed to irreversible collapsing of some clay plates when excess water was removed by oven drying at 110° C.

The d-spacing from X-ray film indicated some bentonite was present in the >2.0 micron fraction, along with numerous impurities. Impurities were absent in the 0.2 to 0.08 and <0.08 micron fractions and these fractions were concluded to be pure bentonite.

Hydrogen peroxide treatment reduced specific surface area. Organic matter in surface horizons and horizons at 5-foot depths exposed 1020 and 1893 square meters surface per gram, respectively. The organic matter throughout the profile exposed, on the average, 1791 square meters surface per gram. The average reduction of surface area due to H_2O_2 treatment was 15.5 and 5.3 square meters per gram soil for the surface and the 5-foot depth horizons, respectively.

The data were interpreted to estimate moisture retained at 1/3 and 15 atmospheres tension. Regression equations 6 through 13 can be used to make these estimates. Moisture is estimated best by using four soil variables: sand, silt, clay, and organic matter in the equation. The estimate of percent moisture was nearly as good when only percent clay and sand instead of the four soil variables were used as the basis for estimation. The use of four variables instead of two improved the prediction

efficiency only 6.5 and 2.4 percent for the 1/3 and 15 atmosphere levels, respectively.

Percent water retained at 1/3, 1.0, 4.0, and 15 atmospheres tension was more closely related to surface area (Table 6) than percent clay (Table 5).

There was a definite relationship between percent clay and range of available water (Table 12). Percent silt was not related to range of available water.

CONCLUSIONS

The proposed equilibrium method was as accurate and more rapid than Sor and Kemper's method for estimating total hydrateable surface areas of soils.

Moisture at field capacity and permanent wilt point can be estimated from data on the physical properties of soils. Under laboratory conditions, without the aid of moisture retention equipment, surface area can be used to estimate moisture at 1/3 and 15 atmospheres tension with an accuracy of $\pm$ 6.5 and $\pm$ 2.3 percent, respectively. Under field conditions, percent clay and sand can be used to estimate percent moisture at field capacity and permanent wilt point with $\pm$ 5.9 and $\pm$ 2.0 percent accuracy, respectively.

ACKNOWLEDGMENTS

The author wishes to express his gratitude and deepest appreciation to Dr. Hyde S. Jacobs, major instructor, for suggesting the problem and aid in analyzing data and manuscript preparation.

Special acknowledgment is due Dr. R. J. Hanks for guidance and for use of moisture retention equipment, Dr. Roscoe Ellis for interpretation of X-ray data, and Dr. Stanley Wearden for assistance in statistical analyses.

LITERATURE CITED

(1) Barshad, I. Factors effecting the interlayer expansion of vermiculite and montmorillonite with organic substances. Soil Sci. Soc. Amer. Proc. 16:176-182. 1952.

(2) Bouyoucos, G. J. The hydrometer as a new and rapid method for determining the colloidal content of soils. Soil Sci. 23:319-330. 1927.

(3) _____. The hydrometer as a new method for the mechanical analysis of soils. Soil Sci. 23:343-352. 1927.

(4) _____. A comparison of the hydrometer method and pipette method for making mechanical analysis of soils, with new directions. Jour. Amer. Soc. Agron. 22:747-751. 1930.

(5) _____. A comparison between the pipette method and the hydrometer method for making mechanical analysis of soils. Soil Sci. 38:335-345. 1934.

(6) _____. Directions for making mechanical analysis of soils by the hydrometer method. Soil Sci. 42:225-229. 1936.

(7) _____. A recalibration of the hydrometer method for making mechanical analysis of soils. Agron. Jour. 43: 434-438. 1951.

(8) Bower, C. A., and F. B. Gschwend. Ethylene glycol retention by soils as a measure of surface area and inter-layer swelling. Soil Sci. Soc. Amer. Proc. 16: 342-345. 1952.

(9) Bower, C. A., and J. O. Goertzen. Surface area of soils and clays by an equilibrium ethylene glycol method. Soil Sci. 87:289-292. 1959.

(10) Bradley, W. F. Molecular associations between montmorillonite and some polyfunctional organic liquids. Jour. Amer. Chem. Soc. 67:975-981. 1945.

(11) Brindley, G. W. X-ray Identification and Crystal Structures of Clay Minerals. London, England. 1951. Enquiries sent to Professor R. E. Grim, Department of Geology, University of Illinois, Urbana, Illinois.

(12) Browning, G. M. Relation of field capacity to moisture equivalent in soils of West Virginia. Soil Sci. 52: 445-450. 1941.

(13) Brunauer, S., P. H. Emmett, and E. Teller. Adsorption of gases in multimolecular layers. Jour. Amer. Chem. Soc. 60:309-319. 1938.

(14) Colman, E. A. A laboratory procedure for determining the field capacity of soils. Soil Sci. 63:277-283. 1947.

(15) Dixon, R. M. The effects of irrigation on the chemical properties of some north central and southwestern Kansas soils. M. S. thesis, Kansas State University, Manhattan, Kansas. 1960.

(16) Dyal, R. S., and S. B. Hendricks. Total surface of clays in polar liquids as a characteristic index. Soil Sci. 69:421-432. 1950.

(17) Finney, D. J. An Introduction to Statistical Science in Agriculture. Printed in Denmark, for sale by John Wiley and Sons, Inc., New York. 1953.

(18) Haise, H. R., H. J. Haas, and L. R. Jensen. Soil moisture studies of some Great Plains soils: II. Field capacity as related to 1/3 atmosphere percentage, and "Minimum Point" as related to 15 and 26 atmosphere percentages. Soil Sci. Soc. Amer. Proc. 19:20-25. 1955.

(19) Jackson, M. L. Soil Chemical Analysis Advanced Course. Published by the author. Madison 6, Wisconsin. 1956.

(20) _____. Soil Chemical Analysis. Prentice-Hall, Inc., Englewood Cliffs, New Jersey. 1958.

(21) Kilmer, V. J., and L. T. Alexander. Methods of making mechanical analyses of soils. Soil Sci. 69:15-24. 1949.

(22) Lund, Z. F. Available water-holding capacity of alluvial soils in Louisiana. Soil Sci. Soc. Amer. Proc. 23:1-3. 1959.

(23) MacEwan, D. M. C. Complexes of clays with organis compounds: I. Faraday Soc. Trans. 44:349-368. 1948.

(24) Martin, R. T. Ethylene glycol retention by clays. Soil Sce. Soc. Amer. Proc. 19:160-164. 1955.

(25) Naddih, B. I. The effect of known quality irrigation water on the chemical properties of soils of western Kansas. M. S. thesis, Kansas State University, Manhattan, Kansas. 1960.

(26) Nelson, R. A., and S. B. Hendricks. Specific surface of some clay minerals, soils, and soil colloids. Soil Sci. 56:285-296. 1943.

(27) Richards, L. A. A pressure membrane extraction apparatus for soil solution. Soil Sci. 51:377-386. 1941.

(28) _____. Pressure-membrane apparatus-construction and use. Agr. Eng. 28:451-454, and 460. 1947.

(29) _____. Porous plate apparatus for measuring moisture retention and transmission by soil. Soil Sci. 66:105-110. 1948.

(30) _____. Methods of measuring soil moisture tension. Soil Sci. 68:95-109. 1949.

(31) Richards, L. A., and M. Fireman. Pressure-plate apparatus for measuring moisture sorption and transmission by soils. Soil Sci. 56:395-404. 1943.

(32) Richards, L. A., and L. R. Weaver. Moisture retention by some irrigated soils as related to soil moisture tension. Jour. Agr. Res. 69:215-235. 1944.

(33) Sor, K., and W. D. Kemper. Estimation of hydrateable surface area of soils and clays from the amount of absorption and retention of ethylene glycol. Soil Sci. Soc. Amer. Proc. 23:105-110. 1959.

(34) Snedecor, G. W. Statistical Methods. Fifth Edition. The Iowa State College Press, Ames, Iowa. 1956.

APPENDIX

Table 8. Saturation percentage, electrical conductivity, cation exchange capacity, and pH of each horizon in 12 soil sites.

Site	Depth	Saturation percent	Electrical conductivity (mmhos./cm.)	Exchange capacity (m.e./100gm.)	Paste
8a	0- 6	45.78	0.642	26.30	7.8
	6-16	51.60	0.656	30.10	7.4
	16-27	51.30	0.708	30.00	7.9
	27-42	46.46	0.714	26.10	7.9
	42-58	43.64	1.131	22.00	7.7
8b	0- 5	31.12	0.500	23.50	7.5
	5-13	45.06	0.741	24.00	7.2
	13-22	41.28	0.417	26.00	7.7
	22-34	41.54	0.370	24.00	7.8
	34-48	42.46	0.392	24.50	7.9
	48-60	38.60	0.459	20.50	7.9
11a	0- 7	42.08	0.578	25.80	7.0
	7-17	55.28	0.803	38.70	7.1
	17-20	52.14	0.640	35.20	7.6
	20-27	51.00	0.523	33.30	7.8
	27-52	50.12	1.678	29.80	7.9
	52-60	50.22	3.378	28.10	7.7
11b	0- 5	39.56	0.839	22.70	6.4
	5-15	54.36	0.672	38.30	6.9
	15-22	55.10	0.742	37.60	7.6
	22-26	51.20	1.107	31.60	7.7
	26-50	49.82	4.064	28.30	7.7
	50-62	46.52	2.270	26.80	7.5
12a'	0-10	40.28	1.425	20.35	7.7
	10-17	41.12	3.714	20.40	7.6
	17-29	39.04	3.556	20.20	7.7
	29-41	37.16	3.667	18.50	7.7
	41-60	34.32	4.725	18.00	7.6
12b	0- 9	41.08	0.511	23.90	7.7
	9-17	36.88	0.433	21.30	7.7
	17-29	37.56	0.514	21.30	7.7
	29-41	37.48	0.556	22.70	7.8
	41-62	34.20	1.656	19.40	7.7

Table 8. (concl.).

Site	Depth	Saturation percent	Electrical conductivity (mmhos./cm.)	Exchange capacity (m.e./100gm.)	Paste
30	0- 7	39.6	0.551	24.5	8.3
	7-12	44.2	0.816	27.0	8.0
	12-24	43.8	0.632	23.5	8.0
	24-40	44.2	0.612	20.5	8.1
	40-60	43.8	0.739	20.5	8.3
31	0- 5	35.2	0.816	21.5	8.3
	5-11	48.1	0.584	26.0	8.1
	11-18	43.6	0.687	24.5	8.1
	18-34	40.6	1.030	23.5	7.8
	34-60	40.1	0.466	23.5	8.1
42	0- 6	46.7	0.712	30.0	8.1
	6- 9	49.2	0.574	31.4	8.3
	9-13	50.0	0.556	25.9	8.4
	13-18	50.5	0.523	30.0	8.1
	18-26	55.8	0.685	27.0	8.3
	26-35	55.4	0.371	27.0	8.3
	35-58	59.2	1.271	35.0	8.0
43	0- 5	48.1	0.636	21.4	7.8
	5-10	51.8	0.324	22.5	7.8
	10-17	56.2	0.434	28.4	7.7
	17-25	51.1	0.494	25.9	8.3
	25-32	51.6	0.890	27.0	8.1
	32-36	49.1	0.680	25.9	8.3
	36-50	56.9	1.148	34.0	8.0
58	0- 8	43.5	0.585	19.5	8.1
	8-16	45.6	0.557	28.5	7.9
	16-25	45.5	0.461	34.5	8.2
	25-32	44.0	0.480	33.0	8.0
	32-44	39.5	0.585	27.0	8.1
	44-56	38.6	0.548	27.0	8.1
59	0- 7	46.6	0.605	27.5	8.1
	7-15	46.0	0.731	34.5	8.0
	15-22	44.1	0.449	33.5	8.2
	22-30	42.8	0.474	30.0	8.0
	30-42	34.6	0.586	27.5	8.2
	42-54	38.6	0.675	27.0	8.3

Table 9. Site location and irrigation history of 12 soils.

Richfield Silt Loam

Site	8a
Owner	Ralph Tuttle
Location	Grant County. About 1320' N and 100' W of SE corner of Sec. 9: T 30-S, R 37-W.
Irrigation	By well for 15 years.
Site	8b
Owner	R. Blehm
Location	Grant County. About 1320' N and 150' E of SW corner of Sec. 10; T 30-S, R 37-W.
Irrigation	None

"Spearville Silty Clay Loam"

Site	11a
Owner	Waldron
Location	Haskell County. About 792' W and about 60' N of SE corner of Sec. 24; T 29-S, R 31-W.
Irrigation	By well since 1948
Site	11b
Owner	Waldron
Location	Haskell County. About 792' W and about 72' S of NE corner of Sec. 25; T 29-S, R 31-W.
Irrigation	None

Table 9 (cont.).

Bayard Clay Loam

Site	12a'
Owner	L. G. Armstrong
Location	Hamilton County. Center of NE¼ of Sec. 35; T 23-S, R 42-W.
Irrigation	By well since 1942
Site	12b
Owner	Baldwin
Location	Hamilton County. About 1650' W and 200' N of SE corner of Sec. 25; T 23-S, 42-W.
Irrigation	None

Ulysses Silt Loam

Site	30
Owner	A. Dyck
Location	Grant County. About 500' S and 100' E of NW corner of SW¼ of Sec. 8; T 28, R 38.
Irrigation	By well since 1941
Site	31
Owner	D. Williams
Location	Grant County. About 1320' N and 100' W of SE corner of SE¼ of Sec. 7; T 28, R 38.
Irrigation	None

Table 9 (concl.).

"Harney Silt Loam"

Site	42
Owner	W. Josserand
Location	Gray County. About 200' S and 50' E from NW corner of NE¼ of Sec. 15; T 28-S, R 30-W.
Irrigation	By well since 1950
Site	43
Owner	W. Josserand
Location	Gray County. About 300' S and 100' W from NE corner of NW¼ of Sec. 5; T 28-S, R 30-W.
Irrigation	None

Kieth Silt Loam

Site	58
Owner	W. Turner
Location	Wallace County. About 800' S and 300' W of NE corner of SW¼ of Sec. 6; T 15-S, R 39-W.
Irrigation	By well since 1950
Site	59
Owner	W. Turner
Location	Wallace County. About 1600' E and 500' N of SW corner of Sec. 6; T 15-S, R 39-W.
Irrigation	None

Table 10. Surface area determined by horizon in 12 sites by two equilibrium methods for natural and H_2O_2 treated soil. Organic matter content is given in each instance.

Richfield Silt Loam

Depth	Surface area: Natural: Proposed method	Natural: Sor & Kemper method	H_2O_2 treated: Proposed method	H_2O_2 treated: Sor & Kemper method	Organic matter in soil: Natural	Organic matter in soil: H_2O_2 treated
inches	$m.^2/gm.$				%	
Site - 8a: SE¼, Sec. 9; T 30-S, R 37-W						
0- 6	182.6	190.4	174.8	184.2	1.60	--
6-16	254.3	251.4	242.1	234.0	1.14	--
16-27	247.6	250.5	226.6	230.4	0.73	--
27-42	248.9	239.5	231.1	240.8	0.74	--
42-58	235.9	223.6	219.1	220.0	0.60	--
Site - 8b: SE¼, Sec. 10, T 30-S, R 37-W						
0- 5	179.7	173.5	161.6	165.8	1.78	--
5-13	257.6	280.9	185.8	188.7	1.27	--
13-22	220.1	216.2	205.5	212.7	0.74	--
22-34	201.4	208.1	206.2	201.7	0.56	--
34-48	213.9	199.4	205.5	207.8	0.44	--
48-60	190.1	181.3	169.7	180.0	0.40	--

Table 10 (cont.).

"Spearville Silty Clay Loam"

Depth inches	Surface area: Natural: Proposed method	Natural: Sor & Kemper method	H_2O_2 treated: Proposed method	H_2O_2 treated: Sor & Kemper method	Organic matter in soil: Natural	Organic matter in soil: H_2O_2 treated
	$m.^2/gm.$				%	
	Site - 11a: SE¼, Sec. 24; T 29-S, R 31-W					
0- 7	178.1	184.2	167.1	175.2	1.71	0.26
7-17	280.9	296.0	285.7	289.9	1.24	--
17-20	265.7	277.3	270.8	257.6	1.01	--
20-27	255.3	246.9	241.7	246.3	0.84	--
27-52	217.2	219.1	214.9	224.3	0.62	--
52-60	213.9	212.0	215.9	213.0	0.62	--
	Site - 11b: NE¼, Sec. 25; T 29-S, R 31-W					
0- 5	147.4	153.2	127.7	137.0	1.47	0.16
5-15	292.8	296.1	257.9	254.3	1.29	0.16
15-22	289.9	293.8	273.7	272.1	0.91	0.57
22-26	229.8	230.4	212.7	221.4	0.74	0.32
26-50	211.0	209.7	195.5	193.2	0.67	0.30
50-62	206.5	208.5	193.6	196.5	0.59	0.18

Table 10 (cont.).

Bayard Clay Loam

Depth	Surface area: Natural: Proposed method	Natural: Sor & Kemper method	H_2O_2 treated: Proposed method	H_2O_2 treated: Sor & Kemper method	Organic matter in soil: Natural	Organic matter in soil: H_2O_2 treated
inches	$m.^2/gm.$				%	
	Site - 12a': NE¼, Sec. 35; T 23-S, R 42-W					
0-10	130.6	121.5	114.4	119.9	1.53	0.30
10-17	133.5	127.7	111.5	121.5	1.12	--
17-29	132.5	134.1	111.5	122.8	0.56	0.17
29-41	119.9	118.9	120.2	120.2	0.46	--
41-60	129.9	120.3	111.2	118.3	0.29	--
	Site - 12b: SE¼, Sec. 25; T 23-S, R 42-W					
0- 9	145.7	145.4	117.0	125.4	2.08	0.20
9-17	122.5	133.1	116.4	113.8	2.28	0.33
17-29	136.7	138.0	130.9	129.0	0.90	0.36
29-41	159.6	168.1	152.9	152.2	0.69	0.28
41-62	126.7	126.4	127.3	131.9	0.37	0.25

Table 10 (cont.).

Ulysses Silt Loam

Depth	Surface area: Natural: Proposed method	Natural: Sor & Kemper method	H_2O_2 treated: Proposed method	H_2O_2 treated: Sor & Kemper method	Organic matter in soil: Natural	Organic matter in soil: H_2O_2 treated
inches	$m.^2/gm.$				%	
	Site - 30: SW¼, Sec. 8; T 28, R 38					
0- 7	197.1	191.6	171.3	179.7	1.66	--
7-12	224.3	234.9	200.0	218.8	1.31	--
12-24	216.5	211.7	196.5	200.7	0.82	--
24-40	194.9	188.4	181.0	182.9	0.66	--
40-60	191.6	189.7	179.4	182.6	0.56	--
	Site - 31: SE¼, Sec. 7; T 28, R 39					
0- 5	183.2	180.0	166.1	170.6	1.63	0.19
5-11	218.1	209.1	216.9	215.9	1.09	0.33
11-18	222.4	216.9	217.8	215.6	1.00	0.33
18-34	203.6	196.2	197.1	215.2	0.67	0.13
34-60	197.8	190.4	194.9	205.2	0.52	0.17

Table 10 (cont.).

Harney Silt Loam

Depth	Surface area: Natural: Proposed method	Natural: Sor & Kemper method	H_2O_2 treated: Proposed method	H_2O_2 treated: Sor & Kemper method	Organic matter in soil: Natural	Organic matter in soil: H_2O_2 treated
inches	$m.^2/gm.$				%	
	Site - 42: NE¼, Sec. 15; T 28-S, R 30-W					
0- 6	181.3	175.5	100.2	106.0	1.95	0.23
6- 9	197.5	200.4	174.2	172.3	1.92	0.29
9-13	244.3	252.4	230.4	229.8	1.48	0.26
13-18	267.9	261.8	241.8	229.5	1.26	0.13
18-26	231.7	233.7	224.3	212.3	0.93	0.10
26-35	236.2	234.0	230.1	208.8	0.76	--
35-58	291.2	285.1	277.3	279.5	0.66	--
	Site - 43: NW¼, Sec. 5; T 28-S, R 30-W					
0- 5	164.1	174.9	138.6	139.9	2.06	0.21
5-10	232.7	236.3	189.4	190.4	1.46	0.20
10-17	266.6	277.6	233.7	238.2	1.04	0.19
17-25	234.6	240.7	215.3	204.3	0.76	0.23
25-32	250.1	242.1	216.5	219.1	0.65	0.18
32-36	250.5	242.1	206.8	212.0	0.57	0.16
36-50	286.7	291.2	247.9	251.1	0.58	--

Table 10 (concl.).

Kieth Silt Loam

Depth	Surface area: Natural: Proposed method	Natural: Sor & Kemper method	H_2O_2 treated: Proposed method	H_2O_2 treated: Sor & Kemper method	Organic matter in soil: Natural	Organic matter in soil: H_2O_2 treated
inches	$m.^2/gm.$				%	
	Site - 58: SW¼, Sec. 6; T 15-S, R 39-W					
0- 8	207.2	209.4	192.9	194.2	1.96	0.26
8-16	261.1	260.2	245.0	242.4	1.35	0.24
16-25	251.7	257.3	246.9	246.0	1.35	0.25
25-32	242.4	244.0	246.6	241.7	0.98	0.29
32-44	196.8	200.0	199.4	193.3	0.54	0.25
44-56	189.3	185.8	185.2	187.4	0.45	0.32
	Site - 59: SW¼, Sec. 6; T 15-S, R 39-W					
0- 7	284.1	276.0	260.8	275.7	1.77	--
7-15	257.6	257.0	256.3	256.9	1.47	--
15-22	250.8	247.6	239.2	242.1	1.38	--
22-30	208.1	210.7	211.7	210.1	0.45	--
30-42	178.1	188.1	190.4	189.7	0.65	--
42-54	173.9	186.5	181.6	182.6	0.53	--
Mean	212.2	212.4	197.1	199.2	1.03	0.24

Table 11. Particle size analysis by hydrometer method, percent sand retained on 300-mesh sieve, and soil class names as determined by Soil Conservation Service Technicians using the "Feel Method" and mechanical analysis (M.A.) for each horizon in 12 soil sites.

Richfield Silt Loam

Depth inches	Hydrometer method: Clay	Silt	Sand (%)	Sand by sieving (%)	Soil class: M.A.	"Feel"
	Site - 8a: SE¼, Sec. 9; T 30-S, R 37-W					
0- 6	25.8	44.8	29.4	28.1	L[1]	SL
6-16	38.4	38.4	23.2	--	CL	SCL
16-27	37.4	38.3	24.3	23.6	CL	SCL
27-42	36.6	37.5	25.9	25.0	CL	SCL
42-58	31.5	42.0	26.5	--	CL	SCL
	Site - 8b: SE¼, Sec. 10; T 30-S, R 37-W					
0- 5	23.0	45.8	31.2	--	L	SCL
5-13	31.2	46.6	22.2	22.0	CL	SCL
13-22	33.0	46.8	20.2	--	CL	SCL
22-34	30.5	50.3	19.2	20.2	SCL	SCL
34-48	28.8	51.4	19.8	--	SCL	SCL
48-60	27.3	49.3	23.4	21.8	CL	CL

"Spearville Silty Clay Loam"

	Site - 11a: SE¼, Sec. 24; T 29-S, R 31-W					
0- 7	27.6	51.0	21.4	20.6	CL	SCL
7-17	40.9	40.5	18.6	16.5	SC	SC
17-20	37.8	46.8	15.4	14.0	SCL	SC
20-27	35.6	47.2	17.2	15.2	SCL	SCL
27-52	27.8	53.7	18.5	18.0	SCL	SCL
52-60	27.6	53.8	18.6	17.4	SCL	SCL
	Site - 11b: NE¼, Sec. 25; T 29-S, R 31-W					
0- 5	22.8	53.3	23.9	--	SL	SCL
5-15	39.1	39.0	21.9	20.1	CL	SC
15-22	40.1	43.9	16.0	--	SC	SC
22-26	36.1	47.7	16.2	15.1	SCL	SCL
26-50	33.3	48.0	18.7	--	SCL	SCL
50-62	32.0	45.6	22.4	--	CL	SCL

[1] Textural Classification symbols follow: SCL = silty clay loam, SL = silt loam, CL = clay loam, SC = silty clay, L = loam, and C = clay.

Table 11 (cont.).

Bayard Clay Loam

Depth inches	Hydrometer method: Clay %	Silt %	Sand %	Sand by sieving %	Soil class: M.A.	"Feel"
Site - 12a': NE¼, Sec. 35; T 23-S, R 42-W						
0-10	18.3	40.9	40.8	40.2	L	CL
10-17	19.4	43.6	37.0	--	L	CL
17-29	19.9	48.2	31.9	--	L	L
29-41	20.5	41.9	37.6	35.8	L	L
41-60	20.0	34.9	45.1	44.1	L	L
Site - 12b: SE¼, Sec. 25; T 23-S, R 42-W						
0- 9	17.6	44.8	37.6	35.2	L	CL
9-17	21.3	35.7	43.0	42.5	L	CL
17-29	24.2	37.4	38.4	37.6	L	L
29-41	27.9	42.7	29.4	28.2	CL	CL
41-62	20.3	40.5	38.2	36.8	L	L

Ulysses Silt Loam

Site - 30: SW¼, Sec. 8; T 28, R 38						
0- 7	27.1	45.8	27.1	26.4	CL	SL
7-12	36.2	42.8	21.0	--	CL	SCL
12-24	35.8	44.6	19.6	18.4	SCL	SCL
24-40	31.3	49.0	19.7	19.0	SCL	SCL
40-60	28.8	53.6	17.6	--	SCL	SCL
Site - 31: SE¼, Sec. 7; T 28, R 38						
0- 5	21.1	45.1	33.8	32.1	L	SL
5-11	31.6	44.2	23.2	--	CL	SCL
11-18	33.2	45.6	21.2	20.5	CL	SCL
18-34	25.7	53.7	20.6	20.2	SL	SCL
34-60	25.8	52.7	21.5	--	SL	SCL

Table 11 (concl.).

"Harney Silt Loam"

Depth	Hydrometer method			Sand by sieving	Soil class	
	Clay	Silt	Sand		M.A.	"Feel"
inches	%			%		
Site - 42: NE¼, Sec. 15; T 28-S, R 30-W						
0- 6	24.4	50.6	25.0	23.8	SL	SCL
6- 9	26.7	47.9	25.4	--	L	SCL
9-13	31.2	44.5	24.3	24.4	CL	SCL
13-18	33.6	40.4	26.0	--	CL	SCL
18-26	33.5	38.6	27.9	25.9	CL	SCL
26-35	33.9	37.8	28.3	--	CL	SCL
35-58	39.6	40.6	19.8	--	SCL	SCL
Site - 43: NW¼, Sec. 5; T 28-S, R 30-W						
0- 5	27.3	50.4	22.3	21.7	CL	SCL
5-10	33.4	42.8	23.8	--	CL	SCL
10-17	37.5	40.4	22.1	--	CL	SCL
17-25	35.2	41.1	23.7	22.9	CL	SCL
25-32	36.2	38.9	24.9	--	CL	SCL
32-36	36.1	40.3	23.6	--	CL	SCL
36-50	43.2	38.9	17.9	18.1	C	SCL

Kieth Silt Loam

Site - 58: SW¼, Sec. 6; T 15-S, R 39-W						
0- 8	28.7	51.0	20.3	19.1	CL	SL
8-16	35.3	47.4	17.3	--	SCL	SCL
16-25	36.2	45.3	18.5	17.2	SCL	SCL
25-32	33.9	47.3	18.8	--	SCL	SCL
32-44	24.4	55.7	19.9	--	SL	SL
44-56	20.3	58.0	21.7	20.1	SL	SL
Site - 59: SW¼, Sec. 6; T 15-S, R 39-W						
0- 7	36.5	43.3	20.2	19.6	CL	SCL
7-15	36.5	44.0	19.5	--	SCL	SCL
15-22	36.4	43.7	19.9	20.0	SCL	SCL
22-30	28.8	39.7	21.5	--	CL	SCL
30-42	21.4	57.0	21.6	20.8	SL	SL
42-54	20.9	57.3	21.8	--	SL	SL

Table 12. Moisture retention at various tensions and range of available water determined by horizon in 12 soil sites.

Richfield Silt Loam

Depth	Water retained				Range of available water
	1/3 atm.	1.0 atm.	4.0 atm.	15 atm.	
inches	%				%
	Site - 8a: SE¼, Sec. 9; T 30-S, R 37-W				
0- 6	31.1	20.9	16.0	14.5	16.6
6-16	35.1	26.0	20.8	20.2	14.0
12-27	34.4	25.8	20.1	18.8	15.6
27-42	35.0	25.0	19.3	16.5	18.5
42-58	35.2	23.4	17.3	15.7	19.5
	Site - 8b: SW¼, Sec. 10; T 30-S, R 37-W				
0- 5	29.3	21.2	14.9	11.5	17.8
5-13	34.7	27.2	21.0	16.6	18.1
13-22	32.2	24.9	19.0	17.8	14.4
22-34	34.2	24.5	17.1	14.8	19.4
34-48	35.9	24.7	16.9	14.3	21.6
48-60	30.7	21.1	14.6	12.5	18.2

"Spearville Silty Clay Loam"

	Site - 11a: SE¼, Sec. 24; T 29-S, R 31-W				
0- 7	31.6	21.5	16.3	14.8	16.8
7-17	38.0	30.5	24.9	19.9	18.1
17-20	36.2	27.7	22.4	17.8	18.4
20-27	36.9	28.0	21.5	19.3	17.6
27-52	36.9	26.6	18.3	15.1	21.8
52-60	36.0	26.2	17.7	15.2	20.8
	Site - 11b: NE¼, Sec. 25; T 29-S, R 31-W				
0- 5	26.4	18.3	13.7	11.7	14.7
5-15	37.6	30.2	23.7	19.1	18.5
15-22	38.0	29.7	24.7	19.6	18.4
22-26	38.6	27.3	22.2	18.8	19.8
26-50	40.4	25.9	17.5	14.5	25.9
50-62	33.8	24.4	17.0	13.7	16.8

Table 12 (cont.).

Bayard Clay Loam

Depth	Water retained				Range of available water
	1/3 atm.	1.0 atm.	4.0 atm.	15 atm.	
inches	%				%
Site - 12a': NE¼, Sec. 35; T 23-S, R 42-W					
0-10	20.2	15.5	10.5	9.3	10.9
10-17	21.8	16.2	11.2	8.1	13.7
17-29	20.7	14.7	10.4	9.1	11.6
29-41	17.6	13.0	9.4	8.2	9.4
41-60	16.8	12.8	9.6	8.4	8.4
Site - 12b: SE¼, Sec. 25; T 23-S, R 42-W					
0- 9	20.5	15.3	11.2	9.9	10.6
9-17	19.4	14.2	10.7	9.1	10.3
17-29	21.8	16.4	11.8	9.9	11.9
29-41	24.0	18.2	13.0	11.1	12.9
41-62	19.0	13.9	10.0	8.4	10.6

Ulysses Silt Loam

Site - 30 SW¼, Sec. 8: T 28, R 38					
0- 7	29.5	21.9	16.4	14.0	15.5
7-12	33.6	26.9	20.2	17.8	15.8
12-24	34.7	25.5	18.8	16.0	18.7
24-40	34.5	23.5	16.3	12.8	21.7
40-60	32.7	24.5	16.4	14.4	18.3
Site - 31: SE¼, Sec. 7; T 28, R 38					
0- 5	24.7	18.7	13.1	11.3	13.4
5-11	31.5	24.6	18.1	16.7	14.8
11-18	32.2	25.5	19.0	17.3	14.9
18-34	33.6	24.3	17.0	14.4	19.2
34-60	34.4	23.8	16.0	13.9	20.5

Table 12 (concl.).

"Harney Silt Loam"

Depth inches	Water retained 1/3 atm.	1.0 atm.	4.0 atm.	15 atm.	Range of available water
	%				%
Site - 42: NE¼, Sec. 15; T 28-S, R 30-W					
0- 6	31.2	21.2	15.6	11.8	19.4
6- 9	32.1	22.8	18.2	15.4	16.7
9-13	38.2	27.5	21.5	15.7	12.5
13-18	36.2	26.8	20.9	16.7	19.5
18-26	32.0	24.1	18.1	16.3	15.7
26-35	31.4	24.1	18.5	16.6	14.8
35-58	40.8	32.0	23.1	19.0	21.8
Site - 43: NW¼, Sec. 5; T 28-S, R 30-W					
0- 5	33.8	21.1	16.0	11.7	22.1
5-10	37.8	25.8	21.3	16.8	21.0
10-17	41.6	28.5	23.2	19.4	22.2
17-25	37.3	25.0	20.0	16.1	21.2
25-32	38.2	25.8	19.6	16.9	21.3
32-36	37.7	25.7	19.6	16.7	21.0
36-60	44.3	31.6	24.5	18.8	25.5

Kieth Silt Loam

Site - 58: SW¼, Sec. 6; T 15-S, R 39-W					
0- 8	32.3	23.4	16.9	14.4	17.9
8-16	36.3	27.2	22.3	17.8	18.5
16-25	38.8	30.7	23.5	19.4	19.4
25-32	38.6	29.2	21.1	18.0	20.6
32-44	33.4	24.0	16.3	12.6	20.8
44-56	29.2	21.4	14.0	11.3	17.9
Site - 59: SW¼, Sec. 6; T 15-S, R 39-W					
0- 7	38.3	29.0	22.7	19.9	18.4
7-15	37.2	28.4	21.7	20.1	17.1
15-22	36.1	29.7	21.4	17.0	19.1
22-30	35.7	26.5	17.6	14.1	21.6
30-42	30.2	22.2	13.7	11.7	18.5
42-54	27.2	20.0	12.6	10.8	16.4

MOISTURE RETENTION CHARACTERISTICS OF SIX WESTERN KANSAS SOILS IN RELATION TO CLAY CONTENT AND SURFACE AREA

by

ROBERT EDWARD MORIN

B. S., Kansas State University
of Agriculture and Applied Science, 1959

AN ABSTRACT OF A THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Agronomy

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1961

A study was made to relate moisture retention characteristics of six western Kansas soils to surface area and clay content. This study was divided into three parts: (a) mechanical analysis of soils, (b) moisture retained at 1/3, 1.0, 4.0, and 15 atmospheres tension, and (c) surface area determinations. Organic matter was determined in natural and H_2O_2 treated soil by the Walkley-Black method.

Sor and Kemper's method was used initially to estimate total surface areas of soils. Preliminary studies, using Sor and Kemper's method to determine specific surface area of soils, indicated the method was very time consuming. An equilibrium method was developed which required less time to determine surface area of soils. Principles used to develop this method were established by Bower and Gschwend, Dyal and Hendricks, and Sor and Kemper.

One phase of this study was to compare the two equilibrium methods used to estimate surface areas of soils. The findings were: (a) surface area can be estimated equally well by both methods, (b) one set of surface area determinations using the proposed method can be made in about half the time required for Sor and Kemper's method, (c) fewer buffer mixtures and less preparation time is required for the proposed method, and (d) fourfold more surface area determinations are made in one run using the proposed method than can be made using Sor and Kemper's method.

Surface area was determined on natural and H_2O_2 treated soil determined by the proposed and Sor and Kemper's method.

The average difference was 0.2 and 2.0 square meters per gram, respectively.

Surface area was determined on each of four size fractions of Wyoming bentonite. The fractionation procedure reduced the specific surface area from 808.6 to 515.5 square meters per gram. The reduction in surface area was attributed to irreversible collapsing of some clay plates when excess water was removed by oven drying at 110° C. The d-spacing from X-ray film indicated some bentonite was present in the >2.0 micron fraction along with numerous impurities. Impurities were absent in the 0.2 to 0.08 and <0.08 micron fractions, and these fractions were concluded to be pure bentonite.

Hydrogen peroxide treatment reduced surface area of soils. The organic matter throughout the profile exposed, on the average, 1791 square meters surface per gram organic matter removed. The average reduction of surface area due to H_2O_2 treatment was 15.5 and 5.3 square meters per gram for the surface and the 5-foot depth horizons, respectively.

The results indicate that various regression equations can be used to estimate moisture retained at 1/3 and 15 atmospheres tension. Moisture is estimated best by using four soil variables: sand, silt, clay, and organic matter in the regression equation. Percent water is estimated nearly as well when only percent clay and sand instead of the four soil variables were used as the basis for estimation.

Percent water retained at 1/3, 1.0, 4.0, and 15 atmospheres tension was more closely related to surface area than percent clay.

The average difference was 0.2 and 2.0 square meters per gram, respectively.

Surface area was determined on each of four size fractions of Wyoming bentonite. The fractionation procedure reduced the specific surface area from 808.6 to 515.5 square meters per gram. The reduction in surface area was attributed to irreversible collapsing of some clay plates when excess water was removed by oven drying at 110° C. The d-spacing from X-ray film indicated some bentonite was present in the >2.0 micron fraction along with numerous impurities. Impurities were absent in the 0.2 to 0.08 and <0.08 micron fractions, and these fractions were concluded to be pure bentonite.

Hydrogen peroxide treatment reduced surface area of soils. The organic matter throughout the profile exposed, on the average, 1791 square meters surface per gram organic matter removed. The average reduction of surface area due to H_2O_2 treatment was 15.5 and 5.3 square meters per gram for the surface and the 5-foot depth horizons, respectively.

The results indicate that various regression equations can be used to estimate moisture retained at 1/3 and 15 atmospheres tension. Moisture is estimated best by using four soil variables: sand, silt, clay, and organic matter in the regression equation. Percent water is estimated nearly as well when only percent clay and sand instead of the four soil variables were used as the basis for estimation.

Percent water retained at 1/3, 1.0, 4.0, and 15 atmospheres tension was more closely related to surface area than percent clay.